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Oak mast history from dendrochronology : a new technique demonstrated in the southern Appalachian region

James Hardy Speer

University of Tennessee

To the Graduate Council:

I am submitting herewith a dissertation written by James Hardy Speer entitled "Oak mast history from dendrochronology : a new technique demonstrated in the southern Appalachian region." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Geography.

Kenneth H. Orvis, Major Professor

We have read this dissertation and recommend its acceptance:

Sally P. Horn, Carol B. Harden, Henri D. Grissino-Mayer, Hazel R. Delcourt

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Vice Provost and
Dean of Graduate Studies

OAK MAST HISTORY FROM DENDROCHRONOLOGY: A NEW TECHNIQUE DEMONSTRATED IN THE SOUTHERN APPALACHIAN REGION

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

James Hardy Speer

December 2001

Dedication

I dedicate this dissertation to my family. Thank you for everything that you have taught me, Collie, Jenna, and Chuck. I also dedicate this dissertation to my wife who was with me from the beginning of this work and who has always provided me with inspiration and support. Thank you, Karla.

Acknowledgements

I would like to thank my major professor and advisor, Dr. Kenneth Orvis, for his support of and insight into this research. He helped me develop the initial study, and his wide knowledge of diverse subject matter has helped me bring together the many aspects of this research from all of science. He was invaluable in his editorial comments as well as his interest in discussing the evolving ideas in this work. I would like to thank my committee members Dr. Carol Harden, Dr. Sally Horn, Dr. Hazel Delcourt, and Dr. Henri Grissino-Mayer for their advice and counsel. Dr. Horn, together with Dr. Orvis, provided me with many research and teaching opportunities that have greatly enhanced my education. Dr. Harden has always been a role model with her excellent research, great administrative skills, and ability to balance her personal life and her academic career. Dr. Delcourt has been an inspiration and great mentor through her advice on my research and through her excellent courses that I have had the privilege to participate in. Dr. Grissino-Mayer has been a valued mentor to me and has provided me with a deeper understanding of dendrochronology than I could have achieved on my own. I would also like to thank him for his services to the dendrochronological community in the form of his Bibliography of Dendrochronology and his tree-ring web pages, both of which I have used extensively.

Thanks go to Dr. Katie Greenberg and the Southern Research Station of the USDA Forest Service for their assistance and generous sharing of data. Dr. Greenberg was extremely generous in allowing me access to her data and to her sample trees, as well as providing logistical help during the field component of this research. I would like to thank the staff at the Bent Creek Experimental Station and thank the administration there for providing me with a field vehicle, increment borers, and a power borer to facilitate sampling the trees. I would also like to thank Dr. Henry McNab for his advice and for sharing data with me. I would like to thank all of the people who helped with the field collections involved in this research: Karla M. Hansen-Speer, Roger Tankersley, Ola Johannsson, Evan Hart, Roger Brown, David Mann, Kevin Anchukaitis, Julia Murphy, Virginia Gibbs, and Norberto Baldi. I would also like to thank David Mann for his work in the laboratory measuring many of the cores incorporated in this study.

Gordon Warburton of the North Carolina Wildlife Resource Commission, Greg Wathen of the Tennessee Wildlife Resources Agency, and David Gregory of the Georgia Department of Natural Resources, Wildlife Resources Division generously shared regional mast data from their respective states. I would also like to thank Mark D. Jones for sharing the North Carolina wild boar and bear data and Scott Osborne for sharing the North Carolina deer harvest data. Thanks go also to Dr. Frank van Manen for providing bear population data and for helpful discussion about the role that acorns play in bear population dynamics.

I would like to thank Dr. Michael Huston and the Environmental Protection Agency for their support through the STAR grant EPA R825157-01-1. This grant provided three and a half years of research stipend as well as money for the purchase of vital equipment. Additional equipment and critical support were provided by a National Science Foundation Doctoral Dissertation Improvement grant (BCS 0000281) to Kenneth

H. Orvis and James H. Speer. The University of Tennessee, Knoxville provided funds for the purchase of a Velmex measuring machine. The Tennessee Geographic Alliance provided funds for a belt sander for the preparation of samples, and the University of Tennessee Laboratory of Tree-Ring Science provided laboratory space and microscopes for the analysis phase of this project.

Chapter 3 has been written with the intention of submitting it to the journal *Tree-Ring Research.* Kenneth H. Orvis and Catheryn H. Greenberg assisted me with formation of the ideas for the research, helped with editing the text, and provided some of the data used in this work. Chapter 4 has been written with the intention of submitting it to the journal *Ecology*. Kenneth H. Orvis, Catheryn H. Greenberg, and Michael A. Huston assisted me with formation of the ideas for the research, helped with editing the text, provided some of the data used in this work, and provided funding for much of the work. Chapter 5 has been written with the intention of submitting it to the *Journal of Wildlife Management*. Frank van Manen, Kenneth H. Orvis, and Catheryn H. Greenberg assisted me with formation of the ideas for the research, helped with editing the text, and provided some of the data used in this work. My use of "we" in these chapters refers to my co-authors and myself.

Abstract

The main objective of this research was to develop a technique for mast reconstruction using dendrochronology. During this work I collected cores from 845 individual trees from white *(Quercus alba*), chestnut *(Q. prinus),* northern red *(Q. rubra)*, black *(Q. velutina)*, and scarlet oaks *(Q. coccinea),* at 17 sites in the southern Appalachians. I identified five basic steps that are necessary for mast reconstruction.

1) Crossdate the tree-ring series;

2) Standardize the series with a flexible cubic smoothing spline;

3) Use multiple regression to remove climate;

4) Use simple linear regression between the climate residuals and a known mast record to define a regression equation;

5) Use the regression equation to reconstruct mast beyond the scope of the known mast record.

From climate analysis of these five oak species grown under closed-canopy conditions, I determined that four of the five species were adequate recorders of Palmer Drought Severity Index and temperature. I developed five mast reconstructions on the stand level explaining from 20% to 47% of the remaining variance in the chronology after climate was removed. At most, 25% of the site-species chronologies showed a reduction in ring width in known years of heavy mast production, which has implications for the theories of mast fruiting. The evolved strategies hypothesis predicts that a tradeoff should be evident between incremental growth and reproductive effort and the

lack of a consistent tradeoff brings this theory into question. I explored the application of mast reconstructions to a problem in wildlife management by comparing two of my reconstructions to a black bear population estimate and black bear harvest records. I found that acorn production from three years prior and the current year correlated significantly with these respective records.

This work demonstrates a new technique for dendrochronology, which I call dendromastecology. It can be applied to other genera and localities around the world to provide information to tree biologists, wildlife ecologists, and mast ecologists. Whether or not future mast reconstructions are successful, they will continue to provide evidence about the tradeoff between incremental growth and reproductive effort.

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Chapter 1

Introduction

Masting is intermittent heavy fruiting by a population of woody plants. Koenig and Knops (2000) hypothesized that oak trees mast in the manner known as "normal masting," which occurs when the trees switch resources from growth to reproduction. This theory predicts that this change in resource allocation should result in a reduced increment of tree growth during the year of a heavy mast event. Tree-ring chronologies should, therefore, record past mast events. My primary research objective is to develop a technique for the reconstruction of mast history using tree rings. Such a technique could potentially provide century-long mast reconstructions that would benefit wildlife science and improve understanding of mast ecology.

Van Dersal (1940) reported that oaks *(Quercus* spp.) provide a food source utilized by more wildlife species than any other genus of woody plant. Many important game species in the southeastern United States feed on acorns, including white-tailed deer *(Odocoileus virginianus),* turkey *(Meleagris gallopavo),* black bear *(Ursa americanus),* and European wild boar *(Sus scrofa).* Oaks serve a crucial role for wildlife as producers of calorie-rich "hard" mast (nuts, including acorns) in late summer and fall (Figure 1-1). That role was once shared with American chestnut (*Castanea dentata* (Marsh.) Borkh.) in the southern Appalachian region, but the near extinction of chestnut during the early

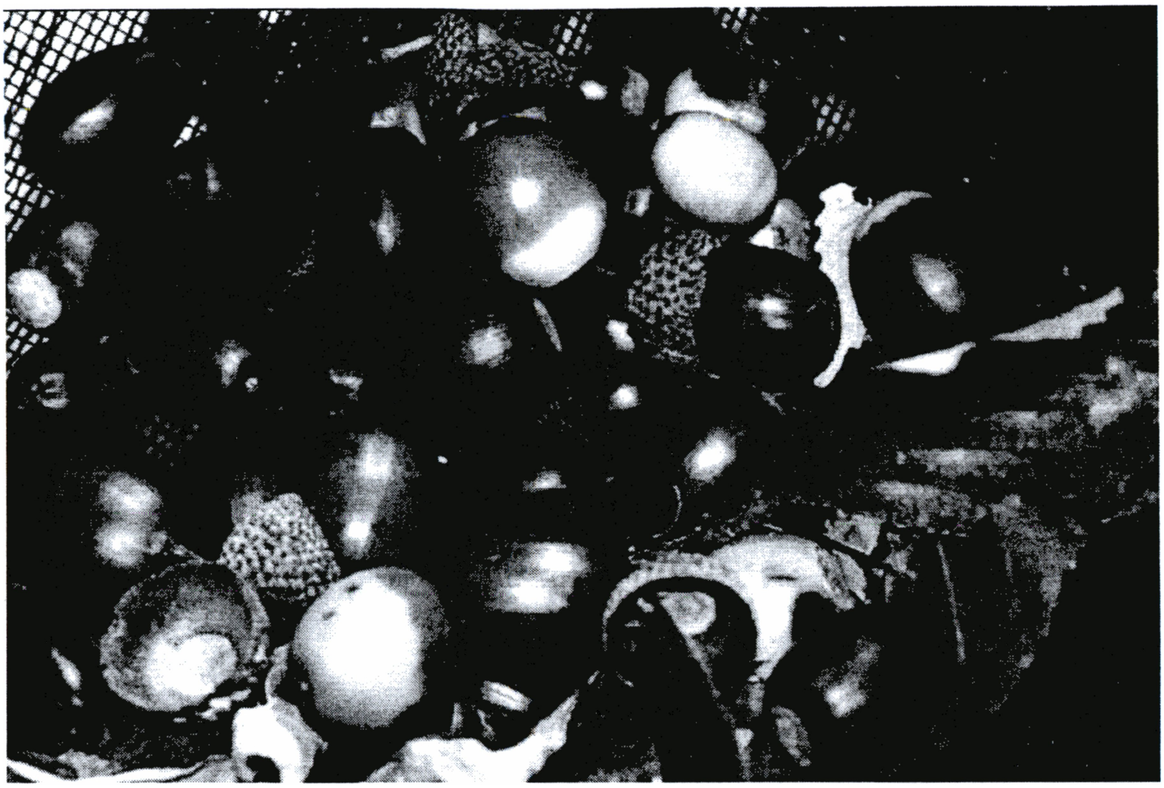


Figure 1-1. Acorns from chestnut oak collected in a mast trap.

1900s shifted wildlife dependence primarily to acorns. Therefore, fluctuations in acorn production should have affected wildlife populations over most of the 20^{th} century.

Oak ecologists can potentially use mast reconstructions to examine past reproductive patterns and compare mast events to stand-age structure, thereby exploring the degree to which masting drives regeneration. Furthermore, mast reconstructions may elucidate whether masting is strongly cyclical due to biological forcing, or dependent upon climatic triggers. Perhaps the most important use of mast reconstruction is to test the "evolved strategies" hypothesis (Norton and Kelly 1988) by determining the existence and extent of any tradeoff between incremental growth and reproductive effort in different species and at different sites. The evolved strategies hypothesis states that mast fruiting is an evolved trait that arose because of forcing factors such as predator satiation or wind pollination so that synchronous fruiting would provide an ecological advantage. This hypothesis predicts that a tradeoff between incremental growth and reproductive effort should exist. Dendrochronological reconstruction of mast history would allow direct testing of this prediction. These varied uses would make mast reconstruction an important tool for dendroecologists.

Schweingruber (1996) suggested that tree-ring analysis might provide a record of past fluctuations in the mast cycle. He noted that as of 1996 no mast reconstruction had been attempted, but it could succeed if "...dendroecological studies can be done on well-defined sites where the known fruiting of single trees can be compared to climatic conditions." That set of circumstances now exists. In this project, I collaborated with Dr. Cathryn H. Greenberg of the Southern Research Station (U.S. Forest Service) who has collected mast data from 931 individual oak trees on National Forest lands in Tennessee, North Carolina, and Georgia (Figure 1-2). This unique data set provides an opportunity to compare six years of mast records on hundreds of individual trees with tree-ring growth responses in those same trees. Also in this area, the states' Wildlife Resource Agencies have been collecting mast data for the past 24 years, providing a longer record of masting on the broad scale. This region is covered by meteorological data from nine National Oceanic and Atmospheric Administration (NOAA) climate divisions (Figure 1-2). At this divisional level, we were able to acquire monthly Palmer Drought Severity Index and temperature data. These data provide the basis for the mast reconstructions in this dissertation.

Dendrochronology is the study of the annual growth of trees as a temporal control and proxy record of the autecological and environmental variables that affect tree growth. It has been used extensively in archaeology (*e.g.*, Douglass 1929; Baillie 1982), climatology (*e.g.*, Fritts 1976; Grissino-Mayer 1996), and geomorphology (*e.g.*, Gardner *et al.* 1983; Smith *et al.* 1994). Ecological investigations have included reconstruction of insect outbreaks (Speer *et al.* 2001), fire history (Swetnam and Baisan 1997), stand age structure (Abrams *et al.* 1995), and masting (Holmsgaard 1958, Eis *et al.* 1965, Chalupka *et al.* 1976, Woodward *et al.* 1994).

A limited number of studies examining the effect of known mast events on tree-ring width have been conducted. Tree-ring growth reduction due to known heavy mast events has been documented in grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl., Eis *et al.* 1965), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt., Woodward *et al.* 1994),

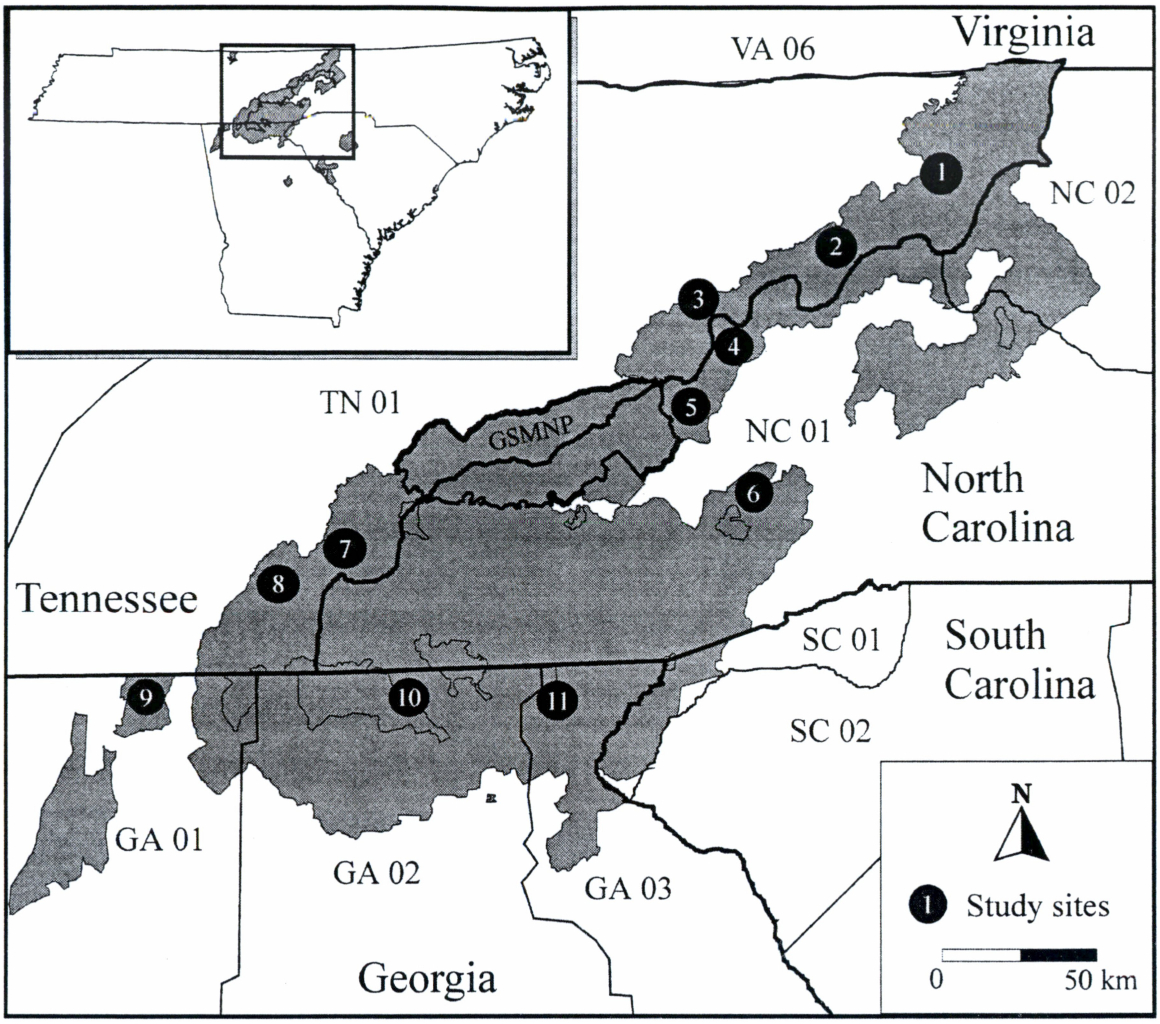


Figure 1-2. Location map of mast sites, National Forests and Parks, and climate divisions in the southern Appalachians. Locations 1 through 11 are sample sites; 1. Watauga, 2. Jackson Farm, 3. Burnett Gap, 4. Mill Ridge, 5. Hurricane Gap, 6. Bent Creek Experiment Forest cluster containing Buell Plot, Bike Trail, Green's Lick, Hard Times, Old Gate, Rice Pinnacle, and South Ridge, 7. Tellico, 8. Hiawassee cluster, 9. Cohutta, 10. Brasstown Work Center, 11. Tallulah. Nine NOAA climate divisions cover the study area; Virginia 6, Tennessee 1, North Carolina 1, North Carolina 2, South Carolina 1, South Carolina 2, Georgia 1, Georgia 2, and Georgia 3. The gray regions designate the National Forest land and the gray region labeled GSMNP is the Great Smoky Mountain National Park.

European beech (*Fagus sylvatica* L., Holmsgaard 1958), Norway spruce (*Picea abies* (L.) Karst., Holmsgaard 1958), Scots pine (*Pinus sylvestris* L., Chalupka *et al.* 1976), western white pine (*Pinus monticola* Dougl. ex D. Don in Lamb., Eis *et al.* 1965), Douglas-fir (*Pseudotsuga menzeisii* (Mirb.) Franco, Eis *et al.* 1965), and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr., Woodward *et al.* 1994). As Schweingruber (1996) noted, however, tree rings have not yet been used to reconstruct past mast events, and oaks have never been examined to determine whether masting reduces incremental growth.

RESEARCH OBJECTIVES

My research has four objectives. Objective (1) tests the hypothesis that the sets of trees I core will display coherent tree-ring chronologies at both stand and regional scales despite the closed-canopy, competitive growing conditions of the trees. Objective (2) tests the prediction of the evolved strategy hypothesis that trees that mast should demonstrate a marked tradeoff between growth and reproductive effort. Objective (3) tests the hypothesis that relationships between masting and residual ring-widths are strong enough to allow the development of convincing numerical reconstruction equations. Objective (4) demonstrates the applicability of mast reconstructions by comparing black bear population estimates to reconstructed fluctuations in acorn production by southern Appalachian oaks.

Objective 1: Establish the local dendrochronological record in oaks

My first objective is to use dendrochronology to develop long-term tree-ring records for five species of southern Appalachian oaks at several widely distributed sites. The underlying principle of dendrochronology is that all trees in a site or region respond to a regional climate signal that affects tree growth similarly. Growth includes radial stem growth, *i.e.* the widths of annual rings. These variations in ring width occur synchronously in different individuals, regardless of age or condition (and to some extent, species). The chronological pattern recorded over many years forms a signature that allows trees to be dated against each other. Dendrochronologists believe that trees grown in a competitive, closed-canopy environment, which is characteristic of the eastern deciduous forest, respond only minimally to climatic forcing factors and would therefore tend to produce poor tree-ring chronologies. This understanding is based on the physiological processes involved in tree growth. Trees growing in closed-canopy conditions are affected by competition with other trees for light, water, and soil nutrients. These endogenous effects can obscure the climate signal (Fritts 1976). Developing multiple oak chronologies from several sites in this environment will enable me to study the climate signal that is obtainable from these closed canopy sites.

Objective 2: Determine the dendrochronological signature of masting in oaks

The evolved strategy hypothesis (Norton and Kelly 1988) states that masting is an evolved trait in response to predator satiation, attracting seed predators, or wind pollination. The hypothesis predicts that there should be a tradeoff between vegetative growth and reproductive effort. Attempting mast reconstructions on 17 sites, with five different species on most sites, provides a robust sample set for assessing the existence and extent of such a tradeoff. The large resource drain caused by masting has been documented in several other genera and species as a reduced production of new wood volume the year(s) that the fruit is on the tree. My second objective is to determine the extent to which oak trees demonstrate this tradeoff between incremental growth and reproductive effort, and to identify any ring-width pattern associated with heavy mast events.

Objective 3: Develop a technique for reconstructing past mast events using the dendrochronological record

Past studies have only shown the effect of masting on ring width through correlation analysis, noting a reduction in ring width the year that seeds are on the trees. I take mast analysis one step further and demonstrate a technique for mast reconstruction, providing a new avenue of research to dendrochronologists. This technique includes the subtraction of climate from the tree-ring chronologies and comparison of the residual chronologies to known mast data (Figure 1-1).

Objective 4: Explore the effect of mast on black bear populations

Acorns have been shown to be a necessary food source for black bears in the fall before the bears enter dens for the winter. Eiler *et al.* (1989) showed low reproductive

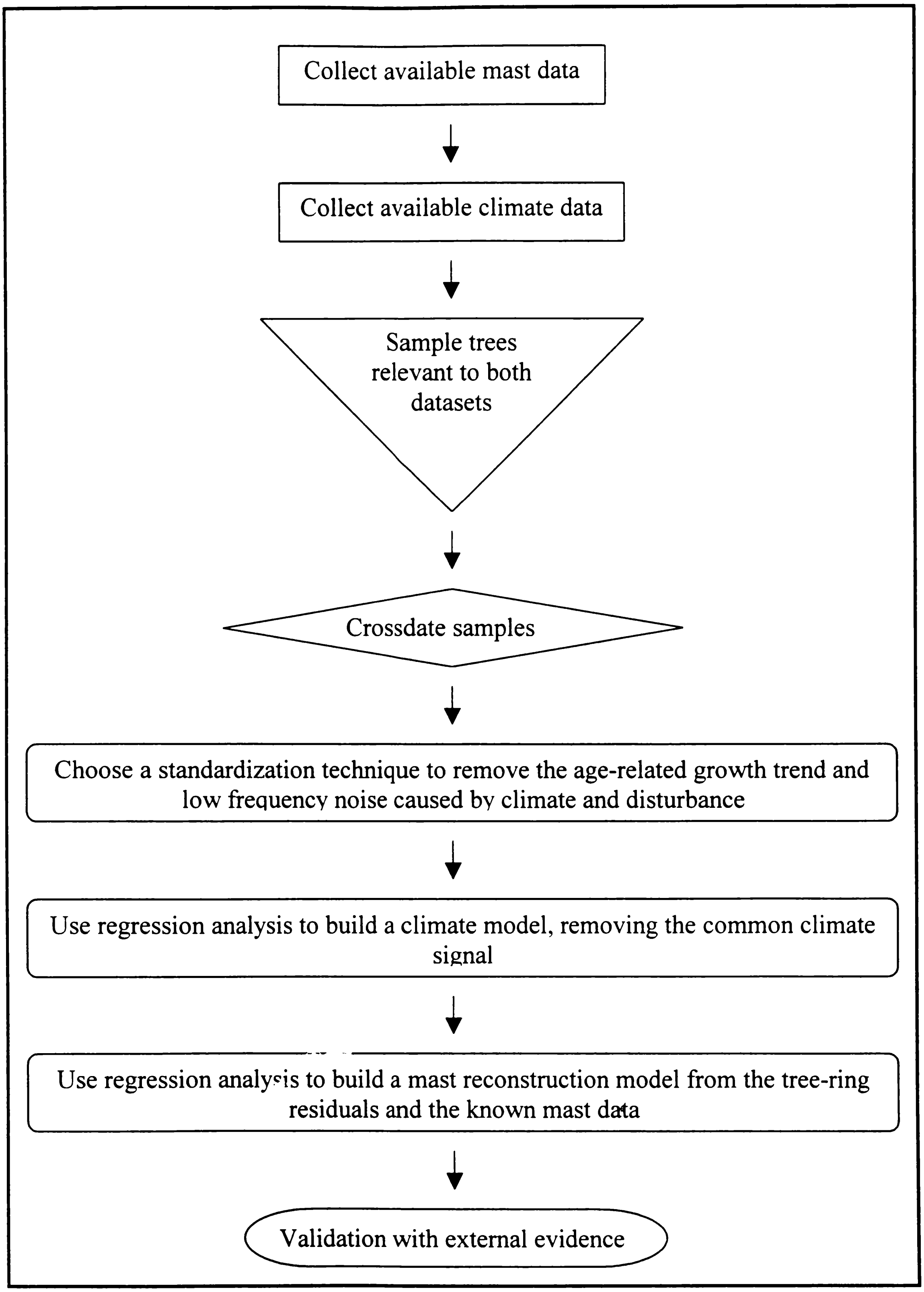


Figure 1-3. The basic steps for a mast analysis.

success (26.1%) and high cub mortality (87.5%) the year after a poor mast event. This suggests that masting cycles in oaks have a significant effect on black bear population dynamics. I test my tentative mast reconstructions by correlating them with black bear population estimates and explore patterns of temporal response. Because bear population data are based only on records of adults and two to three year old juveniles, there should be a lag between masting and any resultant effect on the bear population estimates. Hence, lagged mast data from 2 to 3 years prior to the population measure might reasonably be expected to correlate positively with black bear population estimates. Black bear populations may be influenced by hunting, extreme weather, and disease as well as food availability. Correlation of mast records to black bear population estimates will help to determine how important this food source is to bear populations. This analysis demonstrates the applicability of mast reconstruction to wildlife management.

THE BROADER STUDY AND DISSERTATION ORGANIZATION

My research is part of a larger project under the direction of Dr. Michael Huston (Research Staff, Environmental Sciences Division, Oak Ridge National Laboratory) and funded through a grant from the Environmental Protection Agency (EPA). This project explores ecosystem processes by studying biotic and abiotic factors in concert across various spatial scales. Temperature, precipitation, and soil infiltration data were combined in a hydrologic model, and bear populations and fish communities were analyzed in conjunction with the abiotic factors. My research provides a direct link between the bear population data and the abiotic factors via the fall food resource of oak mast. By understanding long-term dynamics, we can start to understand the effect of masting on bear populations and how climate and autecological cycles drive mast fluctuations, linking the bear population through their food source to the abiotic factors that affect tree growth.

This dissertation is organized so that individual chapters can be published. Chapter 1 introduces the purpose of this dissertation. Chapter 2 provides an in-depth background of the concepts on which this dissertation is based. Chapter 3 presents a dendroclimatological analysis of the five oak species studied. In the process of removing the climate signal from the tree-ring chronologies, I was able to obtain an understanding of response to climate in these five oak species, four of which have seldom been used in climate reconstruction. Chapter 4 presents the techniques for mast reconstruction, including results of successful mast reconstructions that can be used by other researchers. I also test a prediction of the evolved strategies hypothesis. Chapter 5 tests one mast reconstruction against black bear population data from the southern Appalachians. The test demonstrates the potential usefulness of such reconstructions for wildlife management. Chapter 6 includes discussion and conclusions of the dissertation as a whole.

Chapter 2

Background

The study area within the southern Appalachian region includes 17 sites located in eastern Tennessee, western North Carolina, and northern Georgia (Figure 1-2). Bailey (1980) classifies the vegetation as the Eastern Deciduous Forest Province, Appalachian Oak Forest Section. Many co-dominant arboreal species form the canopy including beech (*Fagus grandifolia* Ehrh.), yellow poplar (*Liriodendron tulipifera* L.), basswood (*Tilia heterophylla* Vent.), sugar maple (*Acer saccharum* Marsh.), chestnut (*Castanea dentata* (Marsh.) Borkh.), sweet buckeye (*Aesculus octandra* Marsh.), red oak (*Quercus rubra* L.), white oak (*Quercus alba* L.), and hemlock (*Tsuga canadensis* (L.) Carr.). Birch (*Betula lenta* L.), black cherry (*Prunus serotina* Ehrh.), cucumber tree (*Magnolia acuminata* L.), white ash (*Fraxinus americana* L.), and red maple (*Acer rubrum* L.) are locally abundant with black gum (*Nyssa silvatica* Marsh.), black walnut (*Juglans nigra* L.), and hickories (especially *Carya ovata* (Mill.) K. Koch and *C. cordiformis* (Wangenh.) K. Koch) also occurring frequently. Subcanopy trees include dogwood (*Cornus florida* L.), magnolias (*Magnolia tripetala* L., *M. macrophylla* Michx., and *M. fraseri* Walt.), sourwood (*Oxydendron arborcum* (L.) DC), ironwood (*Ostrya virginiana* (Mill.) K. Koch and *Carpinus caroliniana* Walt.), and American holly (*Ilex opaca* Ait.) (Delcourt 1979).

American chestnut was one of the dominant tree species in the eastern deciduous forest until the chestnut blight (*Cryphonectria parasitica* (Murill) Barr, formerly *Endothia parasitica* (Murr.) A. and A.) extirpated mature chestnut from its natural range in the eastern United States. The chestnut blight first entered the southern Appalachian region around 1926. During the 1930s, chestnut was virtually eliminated from this area (Pyle 1988).

The hard mast produced by chestnut, oaks, beech, hickory, and walnut is an important food source for wildlife in the fall. Chestnut was once the most important mast producer, because it produced a large quantity of edible fruit on a fairly regular basis (Cochran 1990). Since the loss of chestnut, oaks have become the leading hard mast producers and have replaced chestnut trees to become the dominant canopy taxon. Woods and Shanks (1959) found that chestnut oak, northern red oak, and red maple accounted for 46% of the trees in openings created by the demise of chestnut in the Great Smoky Mountains National Park. This change in forest composition has made oaks the dominant arboreal component of this region of the eastern deciduous forest and has shifted the 'burden' of mast production to the oak species.

DENDROCHRONOLOGY IN THE SOUTHEASTERN UNITED STATES

In the southeastern United States, 221 published references have been recorded in the Laboratory of Tree-Ring Research's Bibliography of Dendrochronology (Grissino-Mayer and Butler 1988; Grissino-Mayer 2001). This bibliography has been compiled by Dr. Henri Grissino-Mayer since 1988. The earliest published articles using tree rings in the southeastern United Stated were in the 1880s and 1890s. During this period, four articles were published that dealt with determining the age of trees (Smith 1883; Baldwin 1884; Hotchkiss 1894) and, in one case, dating an earthquake (McGee 1892). Immediately following the 1800s there was a lull in dendrochronological research in the Southeast without another paper published until 1930. Since then, the number of papers published on dendrochronology in the southeastern United States has steadily increased except for another lull in the 1960s (Figure 2-1). The earliest papers dealt mainly with determining the age of trees. In the mid-1900s most of the published papers dealt with climate reconstruction and introducing new methods to the science. In the late 1900s most published papers dealt with ecology and climate reconstructions. Geomorphic and archaeological research has been conducted throughout the history of dendrochronology in this area, although never in great abundance.

The seven most studied species in the Southeast (in order of importance) are bald cypress (*Taxodium distichum* (L.) Rich.; *e.g.* Stahle and Cleaveland 1996), loblolly pine (*Pinus taeda* L. *e.g.* Grissino-Mayer *et al.* 1989), white oak (*Quercus alba* L. *e.g.* LeBlanc 1993; Abrams and Orwig 1996), tulip-poplar (*Liriodendron tulipifera* L. *e.g.* Orwig and Abrams 1994), red spruce (*Picea rubens* Sarg. *e.g.* Cook and Zedaker 1992; McLaughlin *et al.* 1994), northern red oak (*Quercus rubra* L. *e.g.* McCarthy and Bailey 1996), and shortleaf pine (*Pinus echinata* Mill. *e.g.* Grissino-Mayer and Butler 1993) (Table 2-1).

Another source of information concerning dendrochronological research in the southeastern United States comes from the International Tree-Ring Data Bank (ITRDB)

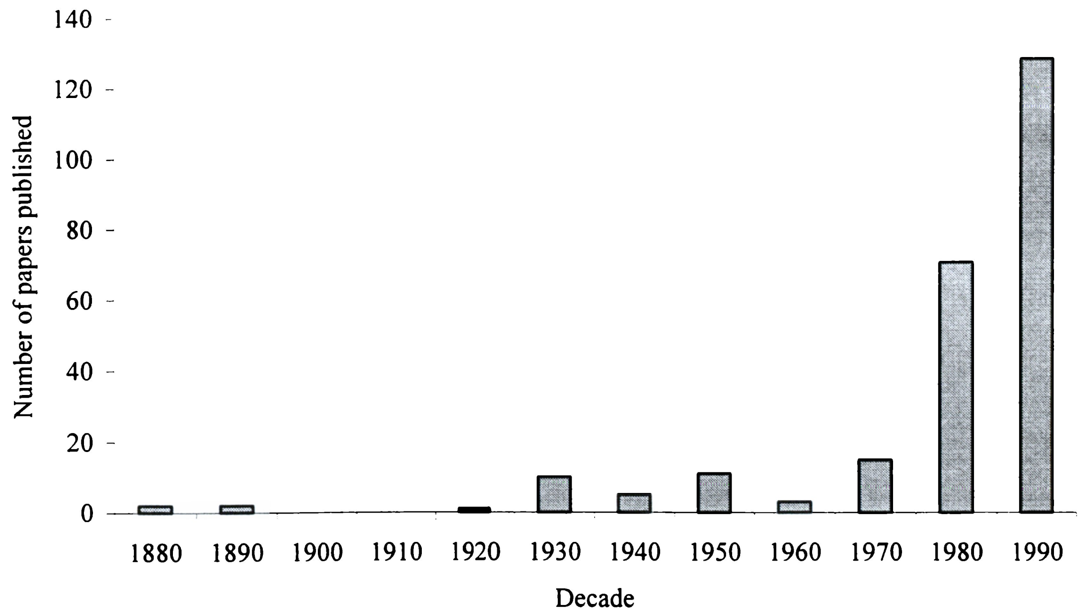


Figure 2-1. The number of dendrochronology articles published on the southeastern U.S. per decade. This data is compiled from the Bibliography of Dendrochronology (Grissino-Mayer 2001).

Table 2-1. Tree species and their frequency of mention in 267 references from the southeastern United States as recorded in the Bibliography of Dendrochronology (Grissino-Mayer 2001). Some of these species may have been mentioned in the article for comparison purposes, so appearance on this list does not necessarily imply that a species was found in the Southeast.

Common Name	***Species***	***Number of published papers mentioning the species***
bald cypress	*Taxodium distichum* (L.) Rich.	43
loblolly pine	*Pinus taeda* L.	31
white oak	*Quercus alba* L.	28
red spruce	*Picea rubens* Sarg.	21
shortleaf pine	*Pinus echinata* Mill.	21
northern red oak	*Quercus rubra* L.	21
tulip-poplar	*Liriodendron tulipifera* L.	20
eastern hemlock	*Tsuga canadensis* (L.) Carr.	19
longleaf pine	*Pinus palustris* Mill.	17
slash pine	*Pinus elliottii* Engelm. var. *elliottii*	12
Virginia pine	*Juniperus virginiana* L.	11
post oak	*Quercus stellata* Wangenh.	11
black oak	*Quercus velutina* Lam.	10
red maple	*Acer rubrum* L.	9
eastern white pine	*Pinus strobus* L.	9
scarlet oak	*Quercus coccinea* Muenchh.	8
sugar maple	*Acer saccharum* Marsh.	7
American beech	*Fagus grandifolia* Ehrh.	7
black gum	*Nyssa sylvatica* Marsh.	7
chestnut oak	*Quercus prinus* L.	7
Fraser fir	*Abies fraseri* (Pursh) Poir.	6
yellow birch	*Betula alleghaniensis* Britton	6
pignut hickory	*Carya glabra* (Mill.) Sweet	6
white ash	*Fraxinus americana* L.	5
sweetgum	*Liquidambar styraciflua* L.	5
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco	5
black birch	*Betula lenta* L.	4
Carolina ash	*Fraxinus caroliniana* Mill.	4
red ash	*Fraxinus pennsylvanica* Marsh.	4
pitch pine	*Pinus rigida* Mill.	4
Virginia pine	*Pinus virginiana* Mill.	4
black cherry	*Prunus serotina* Ehrh.	4
southern red oak	*Quercus falcata* var. *pagodaefolia*	4
sweetbay	*Magnolia virginiana* L.	3
southern bayberry	*Myrica cerifera* L.	3

Table 2-1 (continued).

Common Name	***Species***	***Number of published papers mentioning the species***
redbay	*Persea borbonia* (L.)	3
Scots pine	*Pinus sylvestris* L.	3
balsam fir	*Abies balsamea* (L.) Mill.	2
hazel alder	*Alnus serrulata* (Ait.) Willd.	2
American chestnut	*Castanea dentata* (Marsh.) Borkh.	2
sugarberry	*Celtis laevigata* Willd.	2
buttonbush	*Cephalanthus occidentalis* L.	2
swamp cyrilla	*Cyrilla racemiflora* L.	2
common persimmon	*Diospyros virginiana* L.	2
loblolly-bay	*Gordonia lasianthus* (L.) Ellis	2
dahoon holly	*Ilex cassine* L.	2
large gallberry	*Ilex coriacea* (Pursh) Chapm.	2
inkberry	*Ilex glabra* (L.) Gray	2
western juniper	*Juniperus occidentalis* Hook.	2
cucumbertree	*Magnolia acuminata* L.	2
southern magnolia	*Magnolia grandiflora* L.	2
Ogeechee tupelo	*Nyssa ogeche* Bartr. ex Marsh.	2
sand pine	*Pinus clausa* Vasey ex Sarg.	2
Jeffrey pine	*Pinus jeffreyi* Grev. & Balf.	2
ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.	2
eastern cottonwood	*Populus deltoides* Bartr.	2
laurel oak	*Quercus laurifolia* Michx.	2
blackjack oak	*Quercus marilandica* Muenchh.	2
water oak	*Quercus nigra* L.	2
American basswood	*Tilia americana* L.	2
Carolina hemlock	*Tsuga caroliniana* Engelm.	2
Siberian fir	*Abies sibirica* Ledeb.	1
black mangrove	*Avicennia germinans* (L.) L.	1
gumbo-limbo	*Bursera simaruba* (L.) Sarg.	1
hackberry	*Celtis occidentalis* L.	1
Atlantic white-cedar	*Chamaectparis thyoides* (L.) B.S.P.	1
Florida fiddlewood	*Citharexylum fruticosum* L.	1
bunya beech	*Fagus crenata* Blume	1
beech	*Fagus hayatae* Palib.	1
Japanese beech	*Fagus japonica* Maxim.	1
Mexican beech	*Fagus mexicana* Mart.	1
Oriental beech	*Fagus orientalis* Lipsky	1
European beech	*Fagus sylvatica* L.	1
black walnut	*Juglans nigra* L.	1
Rocky Mountain juniper	*Juniperus scopulorum* Sarg.	1

Table 2-1 (continued).

Common Name	***Species***	***Number of published papers mentioning the species***
huon pine	*Lagarostrobus franklinii* C.J. Quinn	1
red mulberry	*Morus rubra* L.	1
tupelo-gum	*Nyssa aquatica* L.	1
sourwood	*Oxydendrum arboreum* (L.) DC.	1
empress tree	*Paulownia tomentosa* (Thumb.) Steud.	1
Norway spruce	*Picea abies* (L.) Karst.	1
red spruce	*Picea rubens* Sarg.	1
Sitka spruce	*Picea sitchensis* (Bong.) Carr.	1
Rocky Mountain bristlecone pine	*Pinus aristata* Engelm.	1
foxtail pine	*Pinus balfouriana* Grev. & Balf.	1
Caribbean pine	*Pinus caribaea* Mor.	1
Swiss stone pine	*Pinus cembra* L.	1
lodgepole pine	*Pinus contorta* Dougl. ex Loud	1
pinyon	*Pinus edulis* Engelm.	1
limber pine	*Pinus flexilis* James	1
Aleppo pine	*Pinus halepensis* Mill.	1
Hartweg pine	*Pinus hartwegii* Lindl.	1
sugar pine	*Pinus lambertiana* Dougl.	1
bristlecone pine	*Pinus longaeva* D.K. Bailey	1
singleleaf pinyon	*Pinus monophylla* Torr. & Frem.	1
western white pine	*Pinus monticola* Dougl. ex D. Don	1
black pine	*Pinus nigra* Arnold	1
maritime pine	*Pinus pinaster* Aiton	1
Italian stone pine	*Pinus pinea* L.	1
Table Mountain pine	*Pinus pungens* Lamb.	1
red pine	*Pinus resinosa* Ait.	1
southwestern white pine	*Pinus strobiformis* Engelm.	1
American sycamore	*Platanus occidentalis*	1
bigcone Douglas-fir	*Pseudotsuga macrocarpa*	1
holly oak	*Quercus ilex* L.	1
turkey oak	*Quercus laevis* Walt.	1
valley oak	*Quercus lobata* Nee	1
overcup oak	*Quercus lyrata* Walt.	1
bur oak	*Quercus macrocarpa* Michx.	1
sand post oak	*Quercus margaretta* Ashe	1
Montana oak	*Quercus montana* Willd.	1
Nuttall oak	*Quercus nuttallii* Palmer	1
sessile oak	*Quercus petraea* (Mattuschka) Liebl.	1
willow oak	*Quercus phellos* L.	1
downy oak	*Quercus pubescens* Willd.	1

Table 2-1 (continued).

Common Name	***Species***	***Number of published papers mentioning the species***
guiana rapanea	*Rapanea guianensis* Aubl.	1
black locust	*Robinia pseudoacacia* L.	1
Coastal Plain willow	*Salix caroliniana* Michx.	1
sassafras	*Sassafras albidum*	1
giant sequoia	*Sequoiadendron giganteum* (Lindl.) Buchh.	1
West Indies mahogany	*Swietenia mahagoni* Jacq.	1
northern white-cedar	*Thuja occidentalis* L.	1
California nutmeg	*Torreya californica* Torr.	1
Florida torreya	*Torreya taxifolia* Arn.	1

(Grissino-Mayer and Fritts 1997). The ITRDB holds 96 tree-ring chronologies from the southeastern U.S. and 31 of these are from Tennessee, North Carolina, and Georgia. Five of those chronologies were developed from oaks, and all of those were from white oak. The 55 oak chronologies that I have developed in this dissertation will be contributed to the ITRDB so that other researchers can benefit from them.

THE IMPORTANCE OF MAST TO WILDLIFE

Van Dersal (1940) lists 94 species of birds and 92 different mammals in the United States known to feed on oak products including acorns, leaves, and bark. He states that this list greatly underrepresents the numbers of birds and mammals because feeding on oaks is so commonplace that many foresters would not bother publishing a note on their observations. Because of the dependence of these animals on oak mast, the amount of mast each year has been shown to affect the population levels of many wildlife species (Martin *et al.* 1951).

Oaks may act as keystone species, affecting their entire ecosystem through the production of mast. Ostfeld *et al.* (1996) have proposed a conceptual model of how oak mast affects mouse, chipmunk, and deer populations directly. These effects have ramifications for other species and important implications for ecological processes throughout the eastern deciduous forest system. For example, an increase in mouse and squirrel populations can decrease gypsy moths by predation on the pupae. Conversely, higher mouse, chipmunk, and deer populations can increase the occurrence of Lyme disease because these animals are important hosts for larval, nymphal, and adult deer ticks (*Ixodes scapularis*) (Jones *et al.* 1998).

Some studies have found a direct relationship between wildlife populations and mast abundance through time. In a 14-year study, Wolff (1996) found that white-footed mouse (*Peromyscus leucopus*), deer mouse (*P. maniculatus*), and eastern chipmunk (*Tamias striatus*) summer populations correlate strongly with the amount of mast produced the preceding autumn. Another game species that is very dependent upon mast is the European wild boar (*Sus scrofa*). Acorns provide a fatty food source in the fall that the European wild boar needs to achieve reproductive success. Matschke (1967) examined the reproductive organs and stomach of hogs killed on the Tellico Wildlife Management Area, Tennessee from 1959 to 1963 and found that the stomach content of harvested hogs was almost entirely made up of acorns during good mast years. During poor mast years, their stomach content was mainly composed of grasses and other coarse vegetable matter, which are very low in fats and carbohydrates. During the two poorest mast years, only about 5.5% of the sows examined were pregnant, compared to an average of 88.0% in the two best mast years. Matschke (1967) also analyzed the weights of harvested hogs and their fat content. During poor mast years, hogs had a lower average weight, and fat deposits were almost absent.

Bears (*Ursus* spp.) are another example of a genus that is greatly dependent upon hard and soft mast production. Rogers (1976) stated that nutritional factors primarily drive adult black bear (*Ursus americanus*) population fluctuations in northeastern Minnesota. He showed that 16 bears with a body weight of less than 148 pounds before entering their dens produced no cubs while bears above this weight produced cubs in 28 out of 30 cases. Black bears have simple stomachs that are too acid to support the microorganisms needed to digest cellulose. Therefore, black bears cannot digest coarse vegetation very well, and rely mainly on more easily digestible herbs, nuts, berries, buds, catkins, tubers, and meristems that have a high nutritional concentration (Rogers 1976).

Another study of black bears (Eiler *et al.* 1989) found that availability of hard mast affected minimum reproductive age, productivity, and cub survival. Foraging on high quality hard mast causes the most weight gain in black bears. Implantation occurs in the fall, and may be impeded if female black bears are not healthy enough to carry the cubs through the gestation period. All of these physiological mechanisms suggest that availability of hard mast will have a significant effect on black bear populations. Population responses would be expected to lag mast availability because a poor mast year in the fall will affect the number of cubs born in the spring. Survival of the cub through its first year also depends upon successful lactation by the mother, which may be impeded by low weight and poor health. The surviving cubs are not counted in the mature population until age two or three, so it may take two to three years for a heavy (or poor) mast event to show up in bear population estimates.

Mast cycles are important to wildlife, especially bears, because unusual food scarcity at a site can force wildlife to move in search of adequate food (see Rogers 1976; Beecham and Pelton 1980; Garshelis 1994). During poor mast years, bears move farther across the landscape to find sufficient food in October and November before entering their dens (Tankersley 1996), a behavior that brings them into closer contact with humans and other dangers. Because of this, we hypothesize that hunters will take more bears during the year of a poor mast event. This should result in an inverse relationship between mast abundance and bear harvest numbers the same year.

OAK PHENOLOGY

Many factors can affect the acorn crop of any given year. Harsh climate (*i.e.* late spring freezes or summer droughts) one to two years prior to masting could hinder flower bud set, damage flower buds, or abort flowers, thus destroying an acorn crop before pollination even occurs (Sharp and Sprague 1967; Sork *et al.* 1993). The largest drain on the carbon resources for an individual tree should come after the flowers are fertilized, during acorn production. Acorn crops may be limited due to inclement weather affecting the flower buds or flowers in bloom, and would therefore not be evident in the tree-ring record. Because of this, I would expect to find a reduction in ring width only when trees are able to complete acorn production.

Another factor to consider is the reproductive development period of the two subgenera of oak, as this will determine how climatic events will affect mast production. White oak and chestnut oak belong to the subgenus *Leptobalanus*. This subgenus produces flowers in the spring, with the fruit maturing over the summer, culminating in acorn fall in autumn that same year. Northern red, scarlet, and black oaks are in the subgenus *Erythrobalanus*. This subgenus produces flowers in the spring but the fruits remain on the tree for two years, so that the acorns are not mature until the next year's autumn. In both subgenera, both the staminate and pistillate floral buds are actually formed the year prior to flower production so that, depending upon the processes driving fruit production, extreme climatic events can be expected to have important effects on acorn production up to three years later (Sork *et al.* 1993).

Inman (1997) conducted phenological observations on the flowering and fruiting of white oak, chestnut oak, scarlet oak, and northern red oak in the northwest quadrant of the Great Smoky Mountains National Park. Every 1-2 weeks between March and December 1995, he walked four transects noting the flowers or fruit on 5-45 individual trees, depending upon the species. He found that white oak flowered from April 10th to May 8th, and had ripe fruit from September 4th through the end of December, with the peak in fruit development ending on October 31st. Chestnut oak flowered from April 10th to May 8th, and had ripe fruit present from August 21st to October 30th. Scarlet oak flowered from April 10th to May 8th, and had ripe fruit from August 21st through the end of December. Northern red oak flowered from April 10th through May 15th and had ripe fruit from August 21st through the end of December. Fruit are maturing from May until usually October; therefore, the drain of carbon allocation to reproduction occurs during the entire growing season.

Once the acorns are formed, insect predators, especially weevils (*Curculio* sp.), can infest huge numbers of acorns, making them unviable for oak regeneration and degrading the nutritional value of the acorns for wildlife (Beck 1993). Mature acorn crops that are destroyed by insect infestation should produce a similar growth response in the tree as acorn successful crops, because the carbon has already been allocated to acorn production.

POSSIBLE CONFOUNDING FACTORS

Because I attempt to identify past mast events from reductions in ring width, confounding factors could either obscure a mast signal by causing a long-term suppression in ring width at the same time as the mast events, or cause a suppression that may be misinterpreted as a mast signal. The evolved strategy hypothesis (Norton and Kelly 1988) predicts that an extreme mast event will drain the carbon resources of the tree causing one or possibly two years of reduced growth. Many factors can produce such a reduced ring width. Before I can be confident that the identified suppressions are truly due to heavy mast events I must control for these confounding factors.

Natural disturbances are important in the development of the eastern deciduous forest (Pickett and White 1985). High winds and ice storms can cause tree falls and set off a complex process of gap dynamics (Lafon 2000). These disturbances cause relatively long (5-20 years) suppressions and releases in tree-ring series. While these patterns will not be mistaken for a masting signal, the low frequency variation may obscure a masting pattern. A flexible cubic smoothing spline can be used to remove these patterns and enhance interannual variability that may be due to masting (Cook and Peters 1981).

Phytophagous insects remove photosynthetic potential by defoliating trees. This may cause a reduction in ring width as has been shown with spruce budworm (Swetnam and Lynch 1993) and pandora moth (Speer *et al.* 2001). Most defoliating insects cause suppressions that last for many years, which would not be confused with a mast signal. Gypsy moth (*Lymantria dispar* L.) is currently the most common and deleterious defoliator of oaks. To date, the main front of gypsy moths has not reached my study sites, although a few outlying populations occur in the southeastern United States (Johnson and Lyon 1991). Gypsy moth often causes mortality, but even surviving trees usually exhibit at least 10 years of suppressed growth, which would not be confused with a one or two year suppression due to an extreme mast event. Tussock moth (family *Lymantriidae*, of which gypsy moth is an introduced genus) and tent caterpillars (*Malacosoma* spp.) are other common defoliators of oak trees (Johnson and Lyon 1991). These phytophagous insects last at outbreak level from two to six years, causing a suppression that would be more severe and longer-lasting than the effect from heavy mast events.

Fire is another possible confounding factor, although it is not currently a common disturbance in these ecosystems due to successful fire suppression efforts. Historically, fires may have burned more frequently (Abrams 2000), and need to be considered when analyzing ring-width series. Growth suppression has been identified in western forest trees due to fire occurrence (Sutherland *et al.* 1991; Peterson *et al.* 1994), but has not been observed in eastern forests. Oaks can receive a fire scar from surface fires, but they quickly compartmentalize the wound. Part of that compartmentalization process is an increase in ring growth near the wound (Sutherland and Smith 2000). Generally, an increase in ring width may occur around the bole of the tree for about four years following a light surface fire because of nutrient cycling in the soil (Abrams 2000). This release associated with fire is actually the opposite of the signal that we are looking for in association with mast events and therefore cannot be confused with a mast event, although it may override the mast signal.

The most important confounding factor for the identification of a mast signal is the influence of climate on tree growth. Drought can cause a single year of suppression which could be misidentified as a heavy mast event. I attempt to control for this possibility by using climatic reconstruction techniques to remove climate from the site-species chronologies. This procedure should also enhance the mast signal by reducing the noise associated with climate variability.

MAST ECOLOGY

The evolved strategies hypothesis (Norton and Kelly 1988) predicts that trees should demonstrate a tradeoff between incremental growth and reproduction. For example, estimates of the biomass incorporated into beech nuts reach as high as 139% of leaf biomass production and 70% of annual wood-mass production (Nielson 1977). This can cause a 40% growth suppression in years of heavy mast events (Holmsgaard 1958). Eis *et al.* (1965) found similar effects in species of three coniferous genera, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), and western white pine (*Pinus monticola* Dougl. ex D. Don in Lamb.). They examined ring-width data in conjunction with cone count records for a 28-year period, and found that heavy mast events resulted in reduced growth rings the year(s) the cones were on the tree: one year for Douglas-fir and grand fir, two years for western white pine.

Biological mast cycles seem to exist in some oak species. Sork *et al.* (1993) studied flowering and acorn production in black, red, and white oak (same species as in this study) for eight years in east-central Missouri and found distinctive mast cycles in each species. They compared acorn production in the current year with acorn production for the preceding one through four years using each tree (12-15 trees, depending upon species) as a replicate. Black oak tended to produce more mast every two years, white oak every three years, and red oak every four years, so that a mix of species on a site increases the chance of adequate food production. Sork *et al.* (1993) hypothesized that oak trees stored starch and other nutrients during the intervening years. This analysis suggested the existence of mast cycles based on eight years of study, but long-term mast reconstructions would be more able to determine whether longer mast cycles exist and are persistent through time. Sork *et al.* (1993) also found that in all three species the number of flowers produced in spring decreased the year following a heavy mast event, a pattern that they argue is evidence of an evolved mechanism for masting cycles in oaks.

It is possible that natural mast cycles exist because of the necessity of stored reserves for the production of large amounts of mast in a given year. Such cycles might also be reset by climate. Sork *et al.* (1993) found that warm spring temperatures correlated positively with acorn production and summer drought correlated negatively with acorn production in all three species. They suggested that weather affects flowering success and fruit maturation success rather than flower initiation. Apparently, weather can limit acorn production and interrupt the mast cycle, but as long as climatic conditions remain moderate, the tree's intrinsic mast cycle controls crop size.

There is evidence for differences in mast cycles between species in my study area. Individual oak species tended to mast synchronously, but oaks as a whole did not in a study by Inman (1997) of diets of black bear during fall 1995 in the northwestern quadrant of the Great Smoky Mountains National Park. He found that red oaks had produced a heavy acorn crop and provided 69% of the available food calories on his sites, while white oaks experienced a poor mast year and provided only 5%.

These possible patterns in mast cycles and climate triggers provide suggestions for possible forcing mechanisms of mast cycles in my study sites. Long-term mast reconstructions can be used to test the evolved strategies hypothesis by determining whether a tradeoff between incremental growth and reproductive effort exists. Such reconstructions can also be used to test the alternative hypothesis that masting in oaks is simply due to resource matching, in which case significant associations between climate and heavy mast years should be apparent. If mast cycles do exist in southern Appalachian oaks, it is possible that they will not be stable through time as inclement weather periodically resets the cycle.

NATIVE AMERICAN USE OF ACORNS AND LAND USE HISTORY

Native American groups have been present in the southern Appalachians for at least the past 12,000 years (Yarnell 1998). Native Americans have been using acorns as a food source throughout much of their history in North America. Paleoethnobotanical evidence from Cloudsplitter Rockshelter and Cold Oak Shelter, located along the western escarpment of the Cumberland Plateau in eastern Kentucky, showed that acorns were a common food source during the early and late Holocene (9,000 – 8,000 years B.P. and 3,000 – 2,000 years B.P.) (Delcourt *et al.* 1998). Nutshells from acorns, hickories, black walnut, butternut, and chestnut are the most common ethnobotanical remains found during these two periods, indicating their importance as a food source (Delcourt *et al.* 1998). Smith (1929) stated that the human race may have eaten more acorns than it has wheat over the span of human evolution. This may be an overstatement, but acorns have definitely been intensively used, and were an important part of the diets of many prehistoric people prior to the domestication of cereals such as wheat and maize. The nutritional content of acorns and the timing of acorn production just before the lean winter months made them an important food source during the Archaic and Woodland cultural periods in eastern North America.

Native American populations affected the vegetation cover on the landscape through frequent use of fire, and through agricultural practices during the Late Archaic and Early Woodland times (starting around 3,000 B.P.; Delcourt *et al.* 1998). This ancient land use augmented the natural fire regime, possibly increasing the importance of oaks in the vegetation community. One use of a mast reconstruction would be to determine the dependability of mast as a human food source in prehistoric times. For that to be possible, mast reconstructions that extend back more than 200 years would need to be developed. This work is the first step toward such a goal.

HISTORICAL LAND USE

European settlement affected the landscape through farming, logging, and grazing as early as 1795. Varying intensities of logging in the 1800s and 1900s left my study area largely covered with secondary forest. The Southern Appalachian Man and the Biosphere Project determined that the modern landscape is 70% forest, 17.4% pasture, 3.4% cropland, and 3.1% developed (roads and other human settlement features) (SAMAB 1996). This relatively recent removal of mature trees through logging and subsequent regeneration of early-successional forest limits the temporal extent of the dendrochronologic record. Two examples of land use history in my study area follow. They typify land use histories in much of the southern Appalachian region.

Historical land use on the Bent Creek Experimental Forest, NC

The first homestead grant near Asheville, NC was granted to Abraham Randals in 1800 (Nesbitt and Netboy 1946). At that time, Cherokee Indians inhabited the entire Bent Creek Watershed. The forest condition was much different than today with an unbroken, mixed hardwood canopy composed of trees of high quality timber. The undergrowth was much less dense, with reports that it was possible to ride a horse anywhere in the area, even along creeks that are now densely choked by mountain laurel (*Kalmia latifolia* L.) and rhododendron (*Rhododendron maximum* L. or *R. catawbiense* Michx.). Open-range grazing was common until 1885, with cattle, sheep, goats, and hogs browsing on forest herbs, nuts, and seedlings so that the younger age classes of trees were absent. Annual winter burning of the forest understory to improve grazing, destroy insects and snakes, and keep the forest open for hunting was a common practice (Nesbitt and Netboy 1946). This continued until George W. Vanderbilt bought most of the land around 1900 and instituted a policy of fire suppression. The National Forest Service took possession of Bent Creek in 1914. By that time, most of the land had been logged and affected by grazing and fires set by European settlers.

Historical land use in the area of the Great Smoky Mountains National Park (GSMNP)

In the area that is now the Great Smoky Mountains National Park (GSMNP), selective logging occurred from 1880 to 1900. Broad-scale commercial logging started after 1900, and included the use of steam engines, railroads, cable logging, and clearcutting (Pyle 1988). Catastrophic fires often followed intensive logging due to fuel build-up from the logging practices of the time and production of sparks from coal-powered equipment. The Great Smoky Mountains National Park was established in 1934, at which time 63% of the park had been logged or otherwise altered by humans during the preceding century (Pyle 1988). About 9% of the park hosted concentrated settlements where land was cleared for crops and homesteads. Outside of these areas, the effects of settlement were much less damaging to the forest. According to Pyle (1988), at the time of establishment 21% of the park was diffusely disturbed, which she defined as having prevalent livestock grazing or light fires.

These two locales demonstrate how human disturbances have directly affected the vegetation patterns in the region. The whole of the southern Appalachians was similarly affected by logging and settlement, which resulted in a landscape that had been mostly cleared by around 1900. These disturbances have left a landscape that is composed of young to moderately aged trees along with a few remaining stands of old growth. This history of human disturbance makes it difficult to develop dendrochronological records longer than 100 years. Long-term records from southern Appalachian oaks are possible, but they would have to be developed on specific sites selected for their old growth characteristics. In these unique localities, the temporal extent of dendrochronological records is the lifetime of the different oak species, which seem to be from 200 to 300 years (Appendix A). Rapid decay of dead logs in the understory of the eastern deciduous forest generally precludes the possibility of developing longer chronologies from crossdating remnant downed material. The best sources for old wood in the southern Appalachians will probably be the many log cabins located around the landscape.

THE MAST DATA SETS

To reconstruct mast, a modern-day mast data set is needed to compare with ring-width variations to determine the effect of masting on ring width. I was able to acquire data from two different sources, the United States Forest Service (USFS) and the states' Wildlife Resources Agencies (SWRA). Both mast data sets are being collected to examine the dynamics of masting and to study the relationship between mast crops and wildlife populations.

United States Forest Service (USFS) mast data

The U.S. Forest Service's Southern Research Station (SRS), in cooperation with the National Forest system, is collecting a remarkable dataset on the mast crops from 931 individual oak trees (Figure 2-2) (Greenberg 2000). These include five regionally dominant oak species: white oak *(Quercus alba* L.), chestnut oak *(Q. prinus* L.), northern red oak *(Q. rubra* L.), black oak *(Q. velutina* Lam.), and scarlet oak *(Q. coccinea* Muenchh.). Six years of data from 17 study sites on National Forest lands in Tennessee, Georgia, and North Carolina (Figure 1-2) were available for the present study. The USFS technicians record the number of acorns collected from acorn traps that are 0.5 m diameter anchored at one meter above the ground level. Individual trees were selected to include a broad range of ages and topographic positions. This research provides a set of study sites that have a broad spatial distribution and represent a variety of slope angles, aspects, elevations, and substrates. The Forest Service is collecting this site information to determine how the abiotic factors in the environment affect acorn production.

State Wildlife Resource Agency (SWRA) mast data

The Tennessee, North Carolina, and Georgia Wildlife Resources Agencies have been collecting ranked mast data at the county or regional level for the past 23 years. Some years are missing from some counties, but each data set contains a minimum of 15 years, thus providing a longer record of mast than the USFS data. The data are collected

Figure 2-2. Mast traps at tree number 65. Mast traps were established underneath 931 individual oak trees in the southern Appalachians. The traps are constructed of shade cloth draped over a 0.5 m diameter metal ring which is attached to wooden stakes or rebar at a height of one meter. Notice the forest condition during the fall after the trees have lost their leaves and most of the undergrowth has died back.

in all three states following a standard procedure (Whitehead 1969). Permanent transects are walked each year and the amount of hard mast is counted with binoculars on hundreds of randomly selected trees. Subsequently, the strength of the mast year is ranked based on the observations, where zero is assigned for no acorns present and ten is assigned for abundant acorns. This dataset is qualitative but the longer time-series allows more robust statistical analysis of the relationship between tree growth and mast production. Mast data collected from binocular surveys, like the SWRA study, may be a better measure of the effort put into reproduction by the tree than data collected at ground level, because these surveys can count acorns that could potentially be removed by arboreal seed predators. It is also possible that acorns could be removed from mast traps by squirrels and deer, although the traps are constructed to prevent this from occurring.

CONCLUSION

The ability to reconstruct mast would be useful to many fields of research. Wildlife managers could better understand the role that masting plays in population dynamics. Oak ecologists could better understand long-term mast dynamics and the history of regeneration potential in oaks. Mast records may also be useful for understanding the reliability of oak mast as a historic food source for Native Americans.

Oak phenology and mast ecology provide the necessary background to better estimate when a mast event may influence incremental growth. Because of the drain on the tree of energy put into acorn production throughout the growing season, I expect that ring width should be reduced the year of heavy mast production. Previous studies on other genera have demonstrated a reduction in ring width the year of heavy fruit development, but no one has previously developed methods for mast reconstruction. My approach tests the predictions of the evolved strategies hypothesis of masting, which predicts a trade-off between incremental growth and reproductive effort.

Chapter 3

Climate Response of Five Oak Species in the Mixed Hardwood Forest of the Southern Appalachians

INTRODUCTION

Climate reconstruction using dendrochronology has been a standard technique in the western United States since Andrew E. Douglass and Edmund Schulman first reconstructed climate in the American Southwest in the early 1900s (Douglass 1920; Schulman 1944). Since that time, dendroclimatological reconstructions have been developed around the world and have been the basis for a growing understanding of natural climate fluctuations as well as evidence for global climate change (Fritts 1976; Grissino-Mayer 1995; Stahle *et al.* 2000). In the southeastern United States most of the climate research has been conducted on bald cypress (*Taxodium distichum* (L.) Rich., Stahle and Cleaveland 1996), pines (primarily *Pinus taeda* L. and *P. echinata* Mill., Friend and Hafley 1989; Grissino-Mayer *et al.* 1989; Grissino-Mayer and Butler 1993), tulip-poplar (*Liriodendron tulipifera* L., Orwig and Abrams 1997; Pan *et al.* 1997), and white oak (*Quercus alba* L., LeBlanc 1993)(Table 3-1).

Most climate reconstructions are conducted on sensitive sites selected to maximize the signal being studied. For a precipitation reconstruction, preferred sites

Table 3-1. Tree species and their frequency of mention in 93 climate references from the southeastern United States as recorded in the Bibliography of Dendrochronology (Grissino-Mayer 2001). Some species may have been mentioned in the article for comparison purposes, so appearance below does not necessarily imply that a species occurs in the Southeast.

Common Name	***Scientific Name***	***Number of published papers***
loblolly pine	*Pinus taeda* L.	15
bald cypress	*Taxodium distichum* (L.) Rich.	14
shortleaf pine	*Pinus echinata* Mill.	9
white oak	*Quercus alba* L.	9
tulip-poplar	*Liriodendron tulipifera* L.	8
longleaf pine	*Pinus palustris* Mill.	7
post oak	*Quercus stellata* Wangenh.	6
northern red oak	*Quercus rubra* L.	5
eastern hemlock	*Tsuga canadensis* (L.) Carr.	5
black oak	*Quercus velutina* Lam.	5
white ash	*Fraxinus americana* L.	4
eastern red-cedar	*Juniperus virginiana* L.	4
red spruce	*Picea rubens* Sarg.	4
slash pine	*Pinus elliottii* Engelm. var. *elliottii*	4
chestnut oak	*Quercus prinus* L.	4
pignut hickory	*Carya glabra* (Mill.) Sweet	3
scarlet oak	*Quercus coccinea* Muenchh.	3
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco	3
red ash	*Fraxinus pennsylvanica* Marsh.	2
western juniper	*Juniperus occidentalis* Hook.	2
Scots pine	*Pinus sylvestris* L.	2
Virginia pine	*Pinus virginiana* Mill.	2
southern red oak	*Quercus falcata* Michx.	2
Carolina hemlock	*Tsuga caroliniana* Engelm.	2
ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.	2
red maple	*Acer rubrum* L.	1
sugar maple	*Acer saccharum* Marsh.	1
American chestnut	*Castanea dentata* (Marsh.) Borkh.	1
American beech	*Fagus grandifolia* Ehrh.	1
Rocky Mountain juniper	*Juniperus scopulorum* Sarg.	1
huon pine	*Lagarostrobus franklinii* C.J. Quinn	1
sweetgum	*Liquidambar styraciflua* L.	1
cucumbertree	*Magnolia acuminata* L.	1

Table 3-1 (Continued).

Common Name	***Scientific Name***	***Number of published papers***
sourwood	*Oxydendrum arboreum* (L.) DC.	1
Rocky Mountain bristlecone pine	*Pinus aristata* Engelm.	1
foxtail pine	*Pinus balfouriana* Grev. & Balf.	1
lodgepole pine	*Pinus contorta* Dougl. ex Loud	1
pinyon pine	*Pinus edulis* Engelm.	1
limber pine	*Pinus flexilis* James	1
Jeffrey pine	*Pinus jeffreyi* Grev. &	1
sugar pine	*Pinus lambertiana* Dougl.	1
singleleaf pinyon	*Pinus monophylla* Torr. & Frem.	1
red pine	*Pinus resinosa* Ait.	1
southwestern white pine	*Pinus strobiformis* Engelm.	1
eastern white pine	*Pinus strobus* L.	1
black cherry	*Prunus serotina* Ehrh.	1
bigcone Douglas-fir	*Pseudotsuga macrocarpa*	1
laurel oak	*Quercus laurifolia* Michx.	1
overcup oak	*Quercus lyrata* Walt.	1
bur oak	*Quercus macrocarpa* Michx.	1
blackjack oak	*Quercus marilandica* Muenchh.	1
Montana oak	*Quercus montana* Willd.	1
water oak	*Quercus nigra* L.	1
northern white-cedar	*Thuja occidentalis* L.	1
Fraser fir	*Abies fraseri* (Pursh) Poir.	1
yellow birch	*Betula alleghaniensis* Britton	1

include locations in which trees experience drought stress, such as ridge tops, cliff faces, or south-facing slopes (in the northern hemisphere north of the Tropic of Cancer). For a temperature reconstruction, sites located at upper tree line or higher latitudes serve best. In such sites, tree-ring growth is diminished in colder than normal years. Hence, careful site and tree selection by the researcher will maximize the signal to noise ratio and facilitate the identification of different environmental variables.

Our sites were chosen by Forest Service personnel as representatives of different growing conditions that may influence acorn production (mast) in oak trees. This climate analysis is one step in a larger project whose main objective is to develop a technique for reconstructing a record of heavy mast events in the southern Appalachian region. We report here our initial work to gain an understanding of the climate responses of five oak species so that the climate signal can later be removed from the tree-ring chronologies to clarify the mast signal.

Each tree species is sensitive to different climate variables, and this sensitivity will determine what climate parameters can be reconstructed. We report on white oak (*Quercus alba* L.), chestnut oak (*Q. prinus* L.), northern red oak (*Q. rubra* L.), black oak (*Q. velutina* Lam.), and scarlet oak (*Q. coccinea* Muenchh.). We have sampled trees that were selected by technicians of the U.S. Forest Service, Southern Research Station for a comprehensive mast project (directed by Greenberg). Trees and sites were chosen to represent a wide range of tree ages, topographic positions, and site conditions to study the effects of these characteristics on spatial and temporal patterns of acorn production.

This study examines the climatic response of the five oak species represented and is unique in that it compares the climatic response of multiple species on particular sites to the same climate data. Knowledge of the climate response of the dominant oak species in the southern Appalachian forest will help dendroclimatologists in the future understand the relative responses of these species and will illustrate the potential of using trees that, because they have grown in forest interior conditions, have historically been avoided when conducting climate reconstructions.

SITE DESCRIPTION

The Appalachian Mountains are oriented in a northeast-southwest direction and are orthogonal to arctic air outbreaks. The Atlantic Ocean lends a maritime influence to climate on the eastern side of the range, but most of the moisture during the growing season moves northward from the Gulf of Mexico directly along the axis of the Appalachians (Konrad 1996). Much of the climate reflects this broad scale flow over the Appalachian Mountains from the southwest. Micro-topographic effects overprint that pattern to make individual sites relatively dry or wet due to frontal overrunning, orographic uplift, and convective instability (Konrad 1996). This results in a heterogeneous climate on the fine scale, but the gentle grade of the mountain range and the orientation of the range parallel to the dominant path of moisture make the broad-scale climate more homogenous than might be expected in such a mountainous region (D. Loftis pers. comm. USDA Forest Service, Bent Creek Experimental Station).

Our sample sites are located in the Chattahoochee National Forest in northern Georgia, the Pisgah National Forest in western North Carolina, and the Cherokee National Forest in eastern Tennessee. The Forest Service established 17 sites from 1991 to 1993 for the purpose of the mast survey. Three sites are located in northern Georgia (Cohutta, Tallulah, and the Forest Service Work Center outside of Brasstown). Five sites are located in the Cherokee National Forest of eastern Tennessee (Burnett Gap, Hiawassee B, Hiawassee C, Jackson Farm, and Tellico). Nine sites are located in the Pisgah National Forest of western North Carolina, seven in the Bent Creek Experiment Station (Buell Plot, Bike Trail, Green's Lick, Hard Times, Old Gate, Rice Pinnacle, and South Ridge) and two closer to the Tennessee border (Hurricane Gap and Mill Ridge) (Table 3-2; Figure 1-2).

The majority of sites are between 400 and 800 m in elevation, with the lowest site at 270 m and the highest at 1149 m. Vegetation at all sites is classified as Bailey's Eastern Deciduous Forest Province, Appalachian Oak Forest Section (Bailey 1980). American chestnut (*Castanea dentata* (Marsh.) Borkh.) once dominated this class, but the introduced chestnut blight (*Cryphonectria parasitica* (Murill) Barr) decimated the population. Today chestnut has been replaced mainly by chestnut oak, northern red oak, red maple (*Acer rubrum* L.), and tulip poplar (*Liriodendron tulipifera* L.) (Nelson 1955; Woods and Shanks 1959; Young 1996). This change in forest composition leaves oak as the dominant component of the deciduous forest canopy in the southern Appalachian region.

Table 3-2. Site information.

Forest	*Site*	*W Longitude*	*N Latitude*	*Elevation (m)*	*Species*
Pisgah	Bike Trail	82.63	35.52	729	Black, red, scarlet, white oak
Pisgah	Buell Plot	82.63	35.52	695	Chestnut, red, scarlet, white oak
Cherokee	Burnett Gap	82.56	36.22	644	Black, chestnut, red, scarlet, white oak
Chattahoochee	Cohutta	84.78	34.94	441	Chestnut, scarlet, white oak
Pisgah	Green's Lick	82.63	35.52	910	Black, chestnut, red, white oak
Pisgah	Hard Times	82.63	35.52	785	Chestnut, scarlet, white oak
Cherokee	Hiawassee B	84.57	35.34	270	White oak
Cherokee	Hiawassee C	84.57	35.34	481	Black, chestnut oak
Pisgah	Hurricane Gap	82.80	35.88	1149	Chestnut, red, scarlet, white oak
Cherokee	Jackson Farm	82.97	35.97	481	Black, chestnut, red, scarlet, white oak
Pisgah	Mill Ridge	82.97	35.73	732	Chestnut, scarlet, white oak
Pisgah	Old Gate	82.63	35.52	719	Chestnut, scarlet oak
Pisgah	Rice Pinnacle	82.63	35.52	682	Scarlet, white oak
Pisgah	South Ridge	82.63	35.52	828	Chestnut, red, scarlet, white oak
Chattahoochee	Tallulah	83.46	34.92	606	Chestnut, red, white oak
Cherokee	Tellico	84.33	35.38	587	Black, chestnut, red, scarlet, white oak
Chattahoochee	Work Center	83.92	34.93	755	White oak

DIVISIONAL CLIMATE DATA

An aggregate factor, such as Palmer Drought Severity Index (PDSI, Palmer 1965), can better predict tree growth than can precipitation or temperature because it serves as a proxy for water availability (Cook *et al.* 1992; Grissino-Mayer and Butler 1993; Rubino and McCarthy 2000). For our climate reconstructions we examined monthly PDSI data calculated for the nine NOAA climate divisions that cover our study area (Virginia 6, Tennessee 1, North Carolina 1, North Carolina 2, Georgia 1, Georgia 2, Georgia 3, South Carolina 1, and South Carolina 2; Figure 1-2). We also examined divisional temperature data for the same climate divisions.

These nine climate divisions are delimited by state boundaries and topographic barriers. Tennessee Climate Division 1 covers all of Eastern Tennessee ending at the border with North Carolina along the crest of the Appalachian Mountains. This division experiences continental climate and encompasses most of the western side of the southern Appalachians. North Carolina Climate Division 1 covers the southwestern portion of North Carolina and includes all sample sites in that state. This division experiences more influence from maritime tropical air masses off the Atlantic Ocean and encompasses much of the eastern side of the southern Appalachians. Each of our three sites in northern Georgia is located in a different climate division. These climate divisions are all dominated by maritime tropical air masses coming up from the Gulf of Mexico. The influence of the gulf air masses decreases from southwest to northeast.

METHODS

Field methods

Greenberg and personnel of the Southern Research Station (SRS) have collected mast data since 1991 on 931 individual oak trees in Tennessee, North Carolina, and Georgia. Some of the trees in the original data set have died since the study began, and others have not been consistently sampled, so the current data set consists of 664 trees that have at least five years of mast data. Forest Service employees tagged the selected trees and mapped site locations, allowing us to relocate the trees. We took two cores from each of the 845 relocated trees. We cored the trees parallel to the slope contour to avoid the complicating effect of the tree's growth compensation to gravity (gravitropic response). The cores were stored in the field in plastic straws and labeled with the site name and tree number. Because Forest Service personnel had already collected the species information, diameter at breast height (DBH), crown class (dominant, co-dominant, intermediate, or understory), crown size, aspect, slope angle, terrain shape index (TSI), and landform index (LFI) for each tree, our sample number could relate back to this information in their database.

Laboratory methods

We dried all cores at 65° C for 24 hours, mounted them on wooden core mounts, and progressively surfaced them with a belt sander using 120-, 220-, 320-, and 400-grit sandpaper. If the cores retained scratches from sanding that were visible when viewed under magnification (10x-40x), we hand sanded them with 320 grit sandpaper followed by 30 μm sanding film. The sanding film is a different type of sandpaper with a uniform grain size that gives a more uniform finish. The final surface must be clear of scratches so that the cell and ring structure is readily visible under a 10 to 40-power stereozoom microscope.

The dendrochronological analysis followed standard techniques (Stokes and Smiley 1968). For each site, we created skeleton plots from ten cores to develop a master dating chronology. In this chronology, we noted marker rings, which we used to date the remaining samples. We measured the dated cores using a Velmex measuring system at 0.01 mm precision.

We used the program COFECHA to check the dating of the cores (Holmes 1983). This program flags any segments of the measurement series that correlate better in positions other than their dated positions, or whose current match yields a correlation below the expected significance threshold. We went back to the wood to check all flagged segments and make any necessary corrections, until COFECHA and our own analyses of the wood agreed on the dating of the cores.

COFECHA calculates series intercorrelation and average mean sensitivity as measures of the quality of the chronologies. Series intercorrelation measures how well a chronology records a common signal. It is calculated by averaging the correlation coefficients between each tree level chronology and the site master chronology. A high intercorrelation suggests that a strong common signal exists. Mean sensitivity was developed by A. E. Douglass at the beginning of the 1900s and has a strong historical context, which makes it useful for comparing the sensitivity of new sites to past chronologies. Mean sensitivity is a measure of year-to-year variability within a chronology and is used as an indicator of how sensitive tree growth is to environmental fluctuations (Formula I).

$$\textit{Mean sensitivity} = (R_1 - R_2) / ((R_1 + R_2)/2) \qquad \text{[I]}$$

where R_1 is the ring width of the inner ring and R_2 is the ring width of the outer ring. A chronology with a mean sensitivity of 0.2 or higher has been considered adequate for climate reconstruction (Fritts 1976).

We entered the site chronologies into the program ARSTAN to standardize the cores (Cook 1985). The choice of cubic smoothing spline used by ARSTAN to standardize the series determines the temporal frequencies of events that can or cannot be analyzed in the chronology. We determined the best spline to use for our study by creating regional-level species index chronologies using different cubic smoothing splines (100-year, 60-year, 40-year, 35-year, 30-year, 25-year, 20-year, 15-year, 10-year, and 5-year) and determining which chronology maximized the correlation to climate (specifically July PDSI). Because the mast signal is expected to be one year of suppressed growth during the year of a heavy mast event, we felt confident in using a flexible spline to remove variation due to the biological growth trend, disturbance, or competition between trees (Cook and Peters 1981).

Chronology development

Chronologies from individual trees often vary due to competition for light, water, and nutrients, and due to endogenous disturbances. To develop robust stand-level chronologies with little inter-tree variability, we limited site-species chronologies to stands that included five or more trees of a given species. We constructed 55 site-species chronologies: 15 white oak, 13 chestnut oak, 12 scarlet oak, nine northern red oak, and six black oak. The number of individuals per chronology varied from five to 24 trees, with 664 trees included in the final dataset. To develop such stand-level chronologies, ring-width measurements for each core are divided by the standardization curve for that core, and then the two single-core chronologies per tree are averaged to produce tree chronologies. Finally, all tree chronologies of a given species are averaged to produce a site-species chronology. The result is an index chronology that should retain stand-level short-term variability as recorded by the species at the site. We used a series of t-tests to compare the quality of the different species chronologies.

By combining all of the cores from each species into one file, we also developed five regional species chronologies. We then ran ARSTAN on that file again using the 15-year spline. The end result was a set of standard chronologies for each species each of which retains the common variance between all trees and all sites throughout our study area in the southern Appalachians.

Climate data

We compared our five regional-level species chronologies against mean monthly PDSI for all nine of the climate divisions. We also made two aggregate regions, the first by averaging the monthly PDSI values for all nine climate divisions, and the second by averaging the monthly PDSI values for just Tennessee division 1 and North Carolina division 1. These two divisions cover most of the study area and incorporate the mountainous region of the Appalachians (Figure 1-2). Aggregate climate data from Tennessee division 1 and North Carolina division 1 had the highest correlations with our tree-ring index chronologies. We therefore, used the monthly PDSI and monthly temperature values from this aggregate climate division for the whole of the study.

Climate reconstruction

We used correlation matrixes to test associations between climate data and our index chronologies. We used the mean monthly PDSI and temperature from January through October for the year in which the tree ring was formed to determine which months correlated highly with tree growth. We also examined the eight lagged months of May through December of the previous year. In addition, we developed two annual climate parameters. One was the annual mean of temperature and PDSI for the calendar year (January through December); the other was the annual mean of temperature and PDSI for the water year (November of the previous year to November of the current year). We also averaged PDSI and temperature for the current and previous summer months (May through August). In all, we regressed 18 single months, two annual values, and two summer seasonal values of PDSI and temperature (36 variables) against our site-species chronologies. From the resulting matrices we gained an understanding of the climate parameters that affect tree growth on our sites.

Next we used multiple linear regression in SPSS (version 10) (Norusis 1999) to develop a climate model for each of the five regional species chronologies. We examined these models to determine which included variables made climatological and phytological sense, and to assure that we kept our models simple while maximizing the variance explained by climate. This process excluded monthly variables with no known mechanism for affecting tree growth. For the sake of simplicity and consistency in this study, we developed all local models for subtracting climate from the site-species chronologies using the same climate variables, representing the same two climate divisions, that were chosen for the regional species models. We recognize that at a local level, trees are likely to be responding in part to peculiar local climate forcings, but that level of analysis is beyond the scope of this study.

Autocorrelation is a common problem in time series analysis. If a series is highly autocorrelated, it violates one of the assumptions of regression analysis. We used the Durbin-Watson Test to determine the extent to which our tree-ring series are autocorrelated. If the residuals of the regression equation are uncorrelated, the Durbin-Watson (D-W) statistic will be close to 2 (Ostrom 1978); a D-W less than 2 indicates positive autocorrelation and a D-W greater than 2 indicates negative autocorrelation. A D-W between 1.6 and 2.4 is considered good, whereas a time series with a D-W less than

1.2 or greater than 2.8 is considered to be highly autocorrelated. Real time series are most likely to be positively autocorrelated (*i.e.* have a D-W < 2) and are seldom negatively autocorrelated.

RESULTS

Dating quality of the site-species chronologies

The 55 site-species chronologies demonstrated high quality, with an average series intercorrelation of 0.559 (ranges from 0.446 to 0.693) (Figure 3-1) and a mean sensitivity of 0.196 (ranges from 0.140 to 0.266) (Figure 3-2, Table 3-3a-e). Black oak had the highest series intercorrelations among the four species analyzed, while northern red oak had the lowest. Northern red oak yielded significantly lower series intercorrelations than scarlet oak ($t = 2.665$, $p \leq 0.007$) and black oak ($t = 2.698$, $p \leq 0.011$). Black oak yielded significantly higher series intercorrelations than chestnut oak as well ($t = 2.083$, $p \leq 0.033$). However, the chronologies from all five species had relatively high series intercorrelations (lowest intercorrelation for any chronology developed in this study was 0.446).

The mean sensitivity was generally around 0.200 for all of the site-species chronologies. White oak had the highest mean sensitivity (0.216) while all of the other four species groups clustered around 0.189 (Figure 3-2). This suggests that all of these sites are moderately responsive to a variable climate.

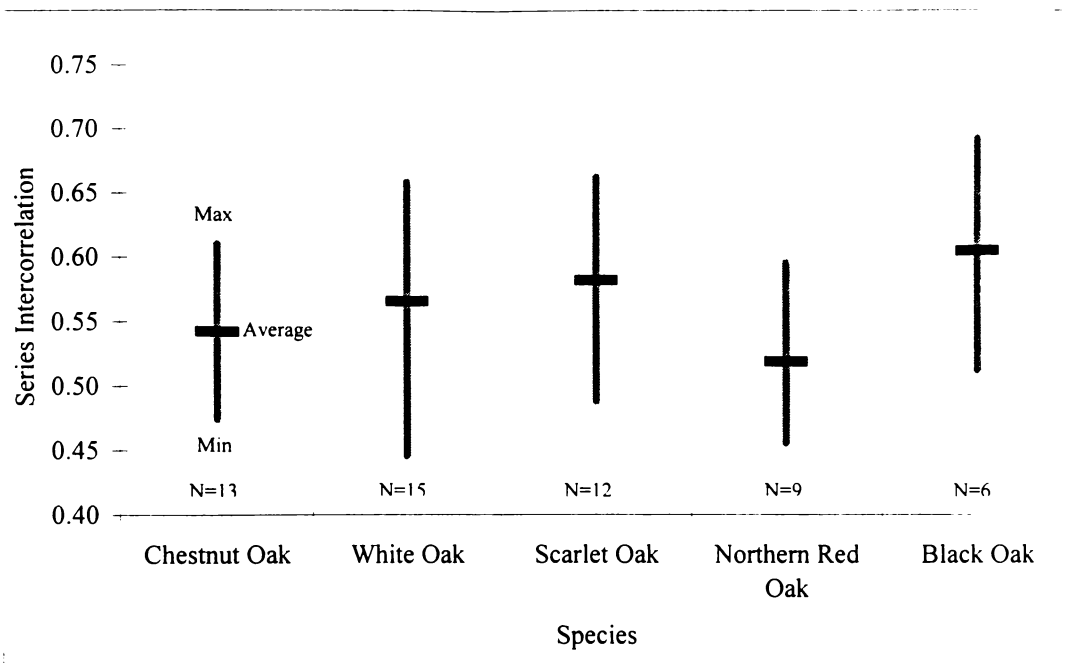


Figure 3-1. Series intercorrelations of the site-species chronologies (bars show the average and range for each species).

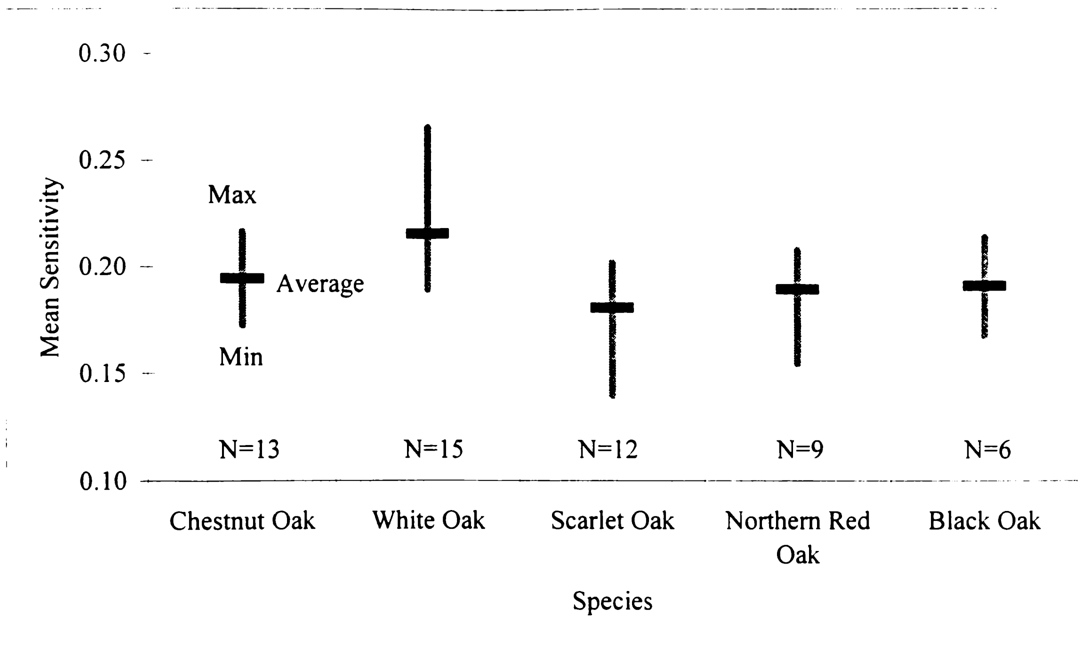


Figure 3-2. Mean sensitivities of the site-species chronologies (bars show the average and range for each species).

Table 3-3. Site-species information and dating quality for a) black oak. The column labeled *years* shows the maximum number of years in the chronology (all chronologies were sampled in 1997, 1998, and 1999). The parameters *series intercorrelation* and *average mean sensitivity* are taken from the COFECHA output and generally describe the quality of the chronology (see main text). The rows marked with a dash designate sites that did not have this species present.

Site	*Number of Trees*	*Number of Cores*	*Years*	*Series intercorrelation*	*Average Mean Sensitivity*
Bike Trail	9	17	186	0.513	0.174
Buell Plot	-	-	-	-	-
Burnett Gap	6	12	152	0.693	0.197
Cohutta	-	-	-	-	-
Green's Lick	6	11	201	0.514	0.168
Hard Times	-	-	-	-	-
Hiawassee B	-	-	-	-	-
Hiawassee C	9	18	170	0.642	0.18
Hurricane Gap	-	-	-	-	-
Jackson Farm	12	24	76	0.572	0.204
Mill Ridge	-	-	-	-	-
Old Gate	-	-	-	-	-
Rice Pinnacle	-	-	-	-	-
South Ridge	-	-	-	-	-
Tallulah	-	-	-	-	-
Tellico	18	36	131	0.651	0.201
Work Center	-	-	-	-	-
Minimum	6	11	76	0.513	0.168
Average	10	20	153	0.598	0.187
Maximum	18	36	201	0.693	0.204

Table 3-3 Continued. b) chestnut oak. The column labeled *years* shows the maximum number of years in the chronology (all chronologies were sampled in 1997, 1998, and 1999). The parameters *series intercorrelation* and *average mean sensitivity* are taken from the COFECHA output and generally describe the quality of the chronology (see main text). The rows marked with a dash designate sites that did not have this species present.

Site	*Number of Trees*	*Number of Cores*	*Years*	*Series intercorrelation*	*Average Mean Sensitivity*
Bike Trail	-	-	-	-	-
Buell Plot	19	38	152	0.552	0.179
Burnett Gap	8	16	114	0.511	0.182
Cohutta	11	22	129	0.587	0.208
Green's Lick	21	42	297	0.480	0.194
Hard Times	18	37	132	0.568	0.181
Hiawassee B	-	-	-	-	-
Hiawassee C	10	20	207	0.588	0.193
Hurricane Gap	18	34	264	0.506	0.201
Jackson Farm	14	24	121	0.504	0.196
Mill Ridge	11	19	136	0.496	0.201
Old Gate	9	18	108	0.556	0.173
Rice Pinnacle	-	-	-	-	-
South Ridge	18	34	129	0.475	0.200
Tallulah	7	14	137	0.555	0.217
Tellico	17	33	145	0.611	0.197
Work Center	-	-	-	-	-
Minimum	7	14	108	0.475	0.173
Average	14	27	159	0.538	0.194
Maximum	21	42	297	0.611	0.217

Table 3-3 Continued. c) northern red oak. The column labeled *years* shows the maximum number of years in the chronology (all chronologies were sampled in 1997, 1998, and 1999). The parameters *series intercorrelation* and *average mean sensitivity* are taken from the COFECHA output and generally describe the quality of the chronology (see main text). The rows marked with a dash designate sites that did not have this species present.

Site	*Number of Trees*	*Number of Cores*	*Years*	*Series intercorrelation*	*Average Mean Sensitivity*
Bike Trail	10	20	135	0.503	0.155
Buell Plot	7	14	65	0.559	0.208
Burnett Gap	5	10	86	0.596	0.183
Cohutta	-	-	-	-	-
Green's Lick	24	46	170	0.467	0.180
Hard Times	-	-	-	-	-
Hiawassee B	-	-	-	-	-
Hiawassee C	-	-	-	-	-
Hurricane Gap	17	33	103	0.465	0.185
Jackson Farm	12	23	64	0.488	0.185
Mill Ridge	-	-	-	-	-
Old Gate	-	-	-	-	-
Rice Pinnacle	-	-	-	-	-
South Ridge	13	24	138	0.456	0.199
Tallulah	17	33	102	0.571	0.208
Tellico	18	35	145	0.571	0.201
Work Center	-	-	-	-	-
Minimum	5	10	64	0.456	0.155
Average	14	26	112	0.520	0.189
Maximum	24	46	170	0.596	0.208

Table 3-3 Continued. d) scarlet oak. The column labeled *years* shows the maximum number of years in the chronology (all chronologies were sampled in 1997, 1998, and 1999). The parameters *series intercorrelation* and *average mean sensitivity* are taken from the COFECHA output and generally describe the quality of the chronology (see main text). The rows marked with a dash designate sites that did not have this species present.

Site	*Number of Trees*	*Number of Cores*	*Years*	*Series intercorrelation*	*Average Mean Sensitivity*
Bike Trail	7	14	98	0.584	0.140
Buell Plot	9	18	126	0.606	0.183
Burnett Gap	11	22	112	0.657	0.197
Cohutta	7	13	95	0.618	0.202
Green's Lick	-	-	-	-	-
Hard Times	5	10	122	0.538	0.189
Hiawassee B	-	-	-	-	-
Hiawassee C	10	20	101	0.607	0.174
Hurricane Gap	-	-	-	-	-
Jackson Farm	12	23	134	0.489	0.184
Mill Ridge	12	24	81	0.546	0.176
Old Gate	14	27	132	0.552	0.166
Rice Pinnacle	19	40	40	0.679	0.224
South Ridge	8	15	110	0.492	0.171
Tallulah	-	-	-	-	-
Tellico	16	31	94	0.638	0.190
Work Center	-	-	-	-	-
Minimum	5	10	40	0.489	0.140
Average	11	21	104	0.584	0.183
Maximum	19	40	134	0.679	0.224

Table 3-3 Continued. e) white oak. The column labeled *years* shows the maximum number of years in the chronology (all chronologies were sampled in 1997, 1998, and 1999). The parameters *series intercorrelation* and *average mean sensitivity* are taken from the COFECHA output and generally describe the quality of the chronology (see main text). The rows marked with a dash designate sites that did not have this species present.

Site	*Number of Trees*	*Number of Cores*	*Years*	*Series intercorrelation*	*Average Mean Sensitivity*
Bike Trail	8	16	281	0.565	0.198
Buell Plot	8	16	221	0.531	0.191
Burnett Gap	9	18	153	0.543	0.235
Cohutta	7	14	113	0.540	0.226
Green's Lick	15	30	290	0.484	0.196
Hard Times	23	45	283	0.637	0.192
Hiawassee B	10	20	114	0.659	0.208
Hiawassee C	-	-	-	-	-
Hurricane Gap	6	11	203	0.495	0.251
Jackson Farm	12	24	90	0.446	0.190
Mill Ridge	12	23	118	0.519	0.218
Old Gate	-	-	-	-	-
Rice Pinnacle	19	37	39	0.658	0.266
South Ridge	7	14	128	0.568	0.218
Tallulah	8	16	189	0.583	0.227
Tellico	18	36	166	0.619	0.223
Work Center	6	12	194	0.623	0.200
Minimum	6	11	39	0.446	0.190
Average	11	22	172	0.565	0.216
Maximum	23	45	290	0.659	0.266

Regional species chronologies

The five regional species chronologies had moderate series intercorrelations (average = 0.431) and mean sensitivities (average = 0.192) (Table 3-4). The overall drop in series intercorrelation is expected because regional climate is not as strong an influence on these trees as the microenvironment in which they live. The trees in each stand are growing under very similar circumstances and have similar controlling factors, including competition and exposure to site-specific climate patterns.

Spline choice and chronology development

By analyzing the climate correlation of each regional species chronology against July PDSI, we determined that a 15-year cubic smoothing spline performed the best (Figure 3-3). In all five species the correlation with July PDSI gradually increased as the spline length was shortened. At the 10- and 5-year splines the correlation started to decrease, so we chose the 15-year spline for all standardization calculations in this study. The 15-year cubic smoothing spline removes low frequency variation and enhances interannual variation, thus increasing the correlation with climate and hopefully maximizing the mast signal. A 15-year spline retains 50% of the variance at 15 years and 99% of the variance at 5 years and below. Therefore, noise from confounding factors with a 5-year or longer trend will be dampened or removed from the chronology, effectively enhancing the expected mast signal (see Figure 3-4 for examples of the standardization technique).

Table 3-4. Dating quality of the regional species chronologies.

Regional Species Chronology	*Number of trees*	*Number of cores*	*Years*	*Series intercorrelation*	*Mean Sensitivity*
Scarlet Oak	132	257	135	0.439	0.182
Northern Red Oak	49	78	171	0.374	0.188
Chestnut Oak	182	351	299	0.415	0.193
White Oak	169	332	291	0.439	0.209
Black Oak	67	129	203	0.486	0.190
Minimum	49	78	135	0.374	0.182
Average	120	229	220	0.431	0.192
Maximum	182	351	299	0.486	0.209
Sum	599	1147			

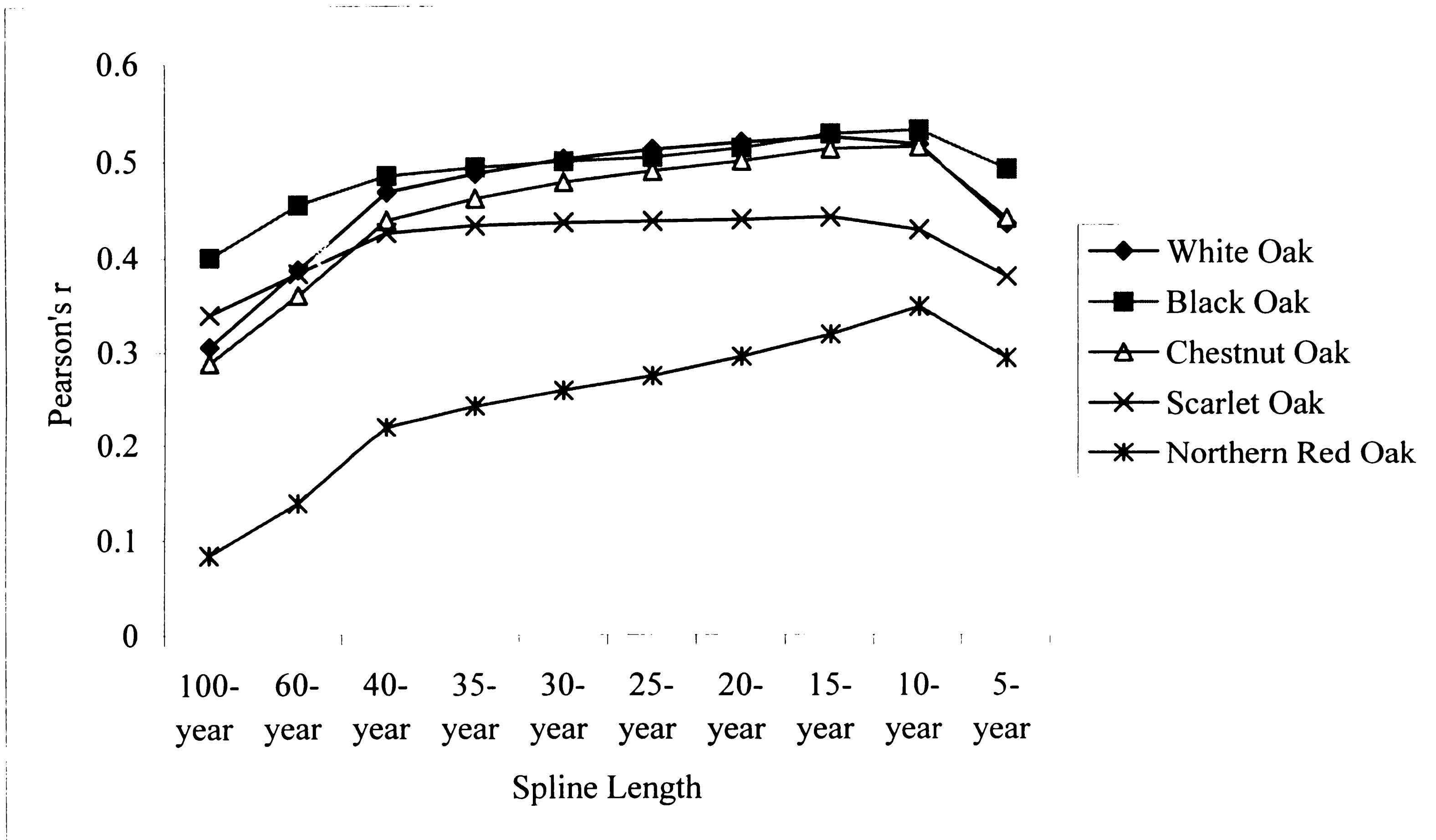


Figure 3-3. Correlation of regional chronologies to climate (two-division mean PDSI; see text) as a function of spline length, by species.

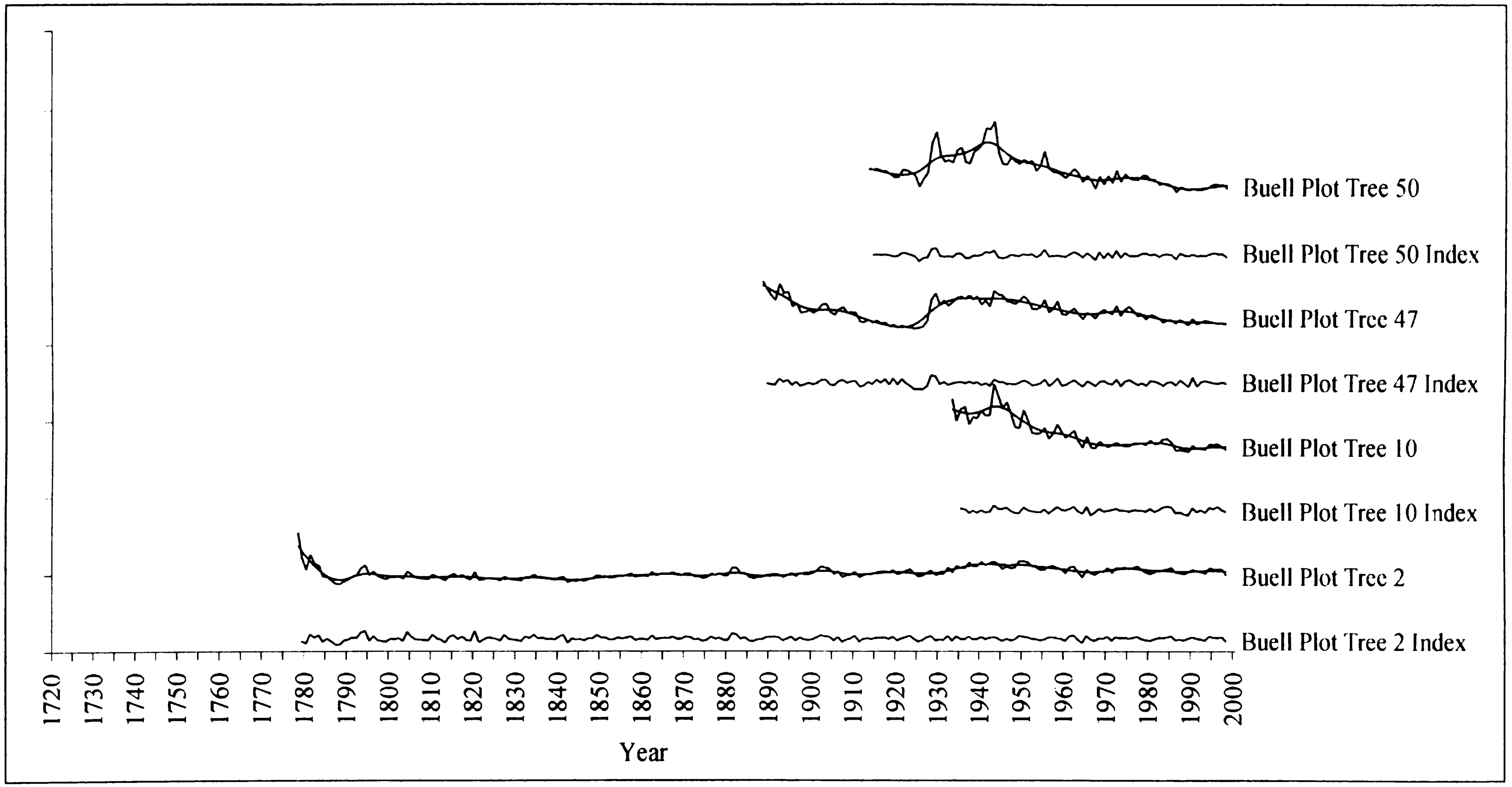


Figure 3-4. Standardization curves for sample white oak trees (continues next page). Each upper curve depicts raw ring-width measurements overlain by the 15-year cubic smoothing spline used to standardize the curve. Lower curves show the resulting standardized index chronologies.

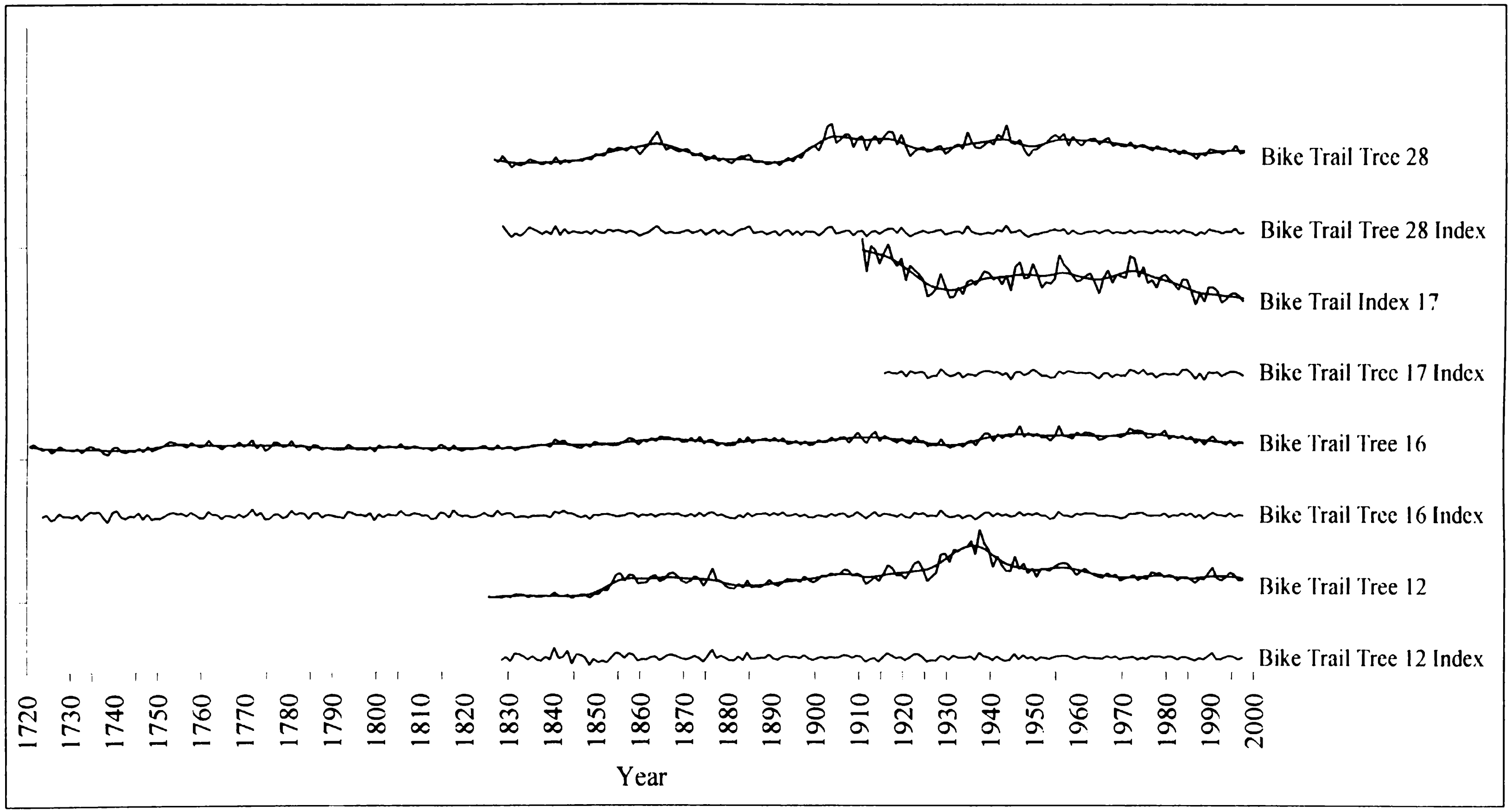


Figure 3-4 (continued).

We developed five regional species chronologies that varied from 134 to 298 years in length (Figure 3-5). The regional white oak chronology was the longest starting in 1701 and ending in 1999. From the 55 standard site-species chronologies that we developed, our longest chronology extends back to 1701 and the shortest started in 1958. The 15-year cubic smoothing spline was successful in removing the age-related growth trend and long-term variability due to disturbance (Figure 3-6).

Analysis of climate response across the landscape

Climate parameters

We were able to develop suitable climate models for all five regional species chronologies using three monthly PDSI or temperature variables (Table 3-5). June or July PDSI was always the first variable chosen for the model (Figure 3-7). Then temperature from May of the previous year and current-year September were almost always chosen (Figure 3-8). June and July PDSI reflect moisture stress during the middle of the growing season and reasonably have the strongest individual correlations with regional species chronologies. The previous year's May temperature reflects the influence of the length of the previous year's growing season on the trees' ability to store nutrients for early spring growth in the current year. Repeatedly, September temperature was negatively correlated with ring width in the regional species chronologies and the site-species chronologies. This suggests that warm temperatures during the end of the growing season limit the amount of growth in the current year. This may be due to water stress in the trees later in the growing season even when PDSI values do not indicate

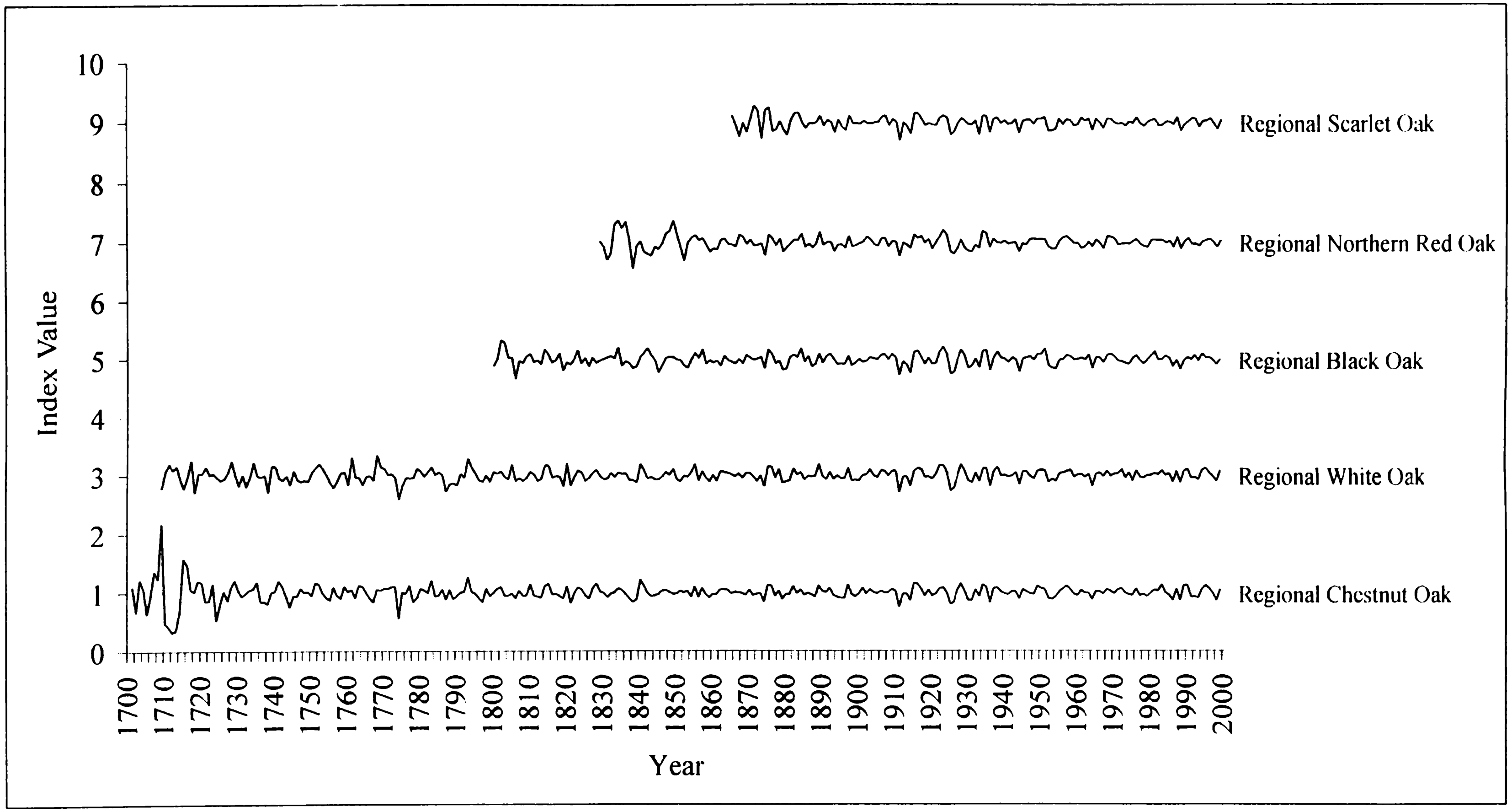


Figure 3-5. Regional index chronologies (arranged in order of length), developed from all single-tree standardized index chronologies of each species.

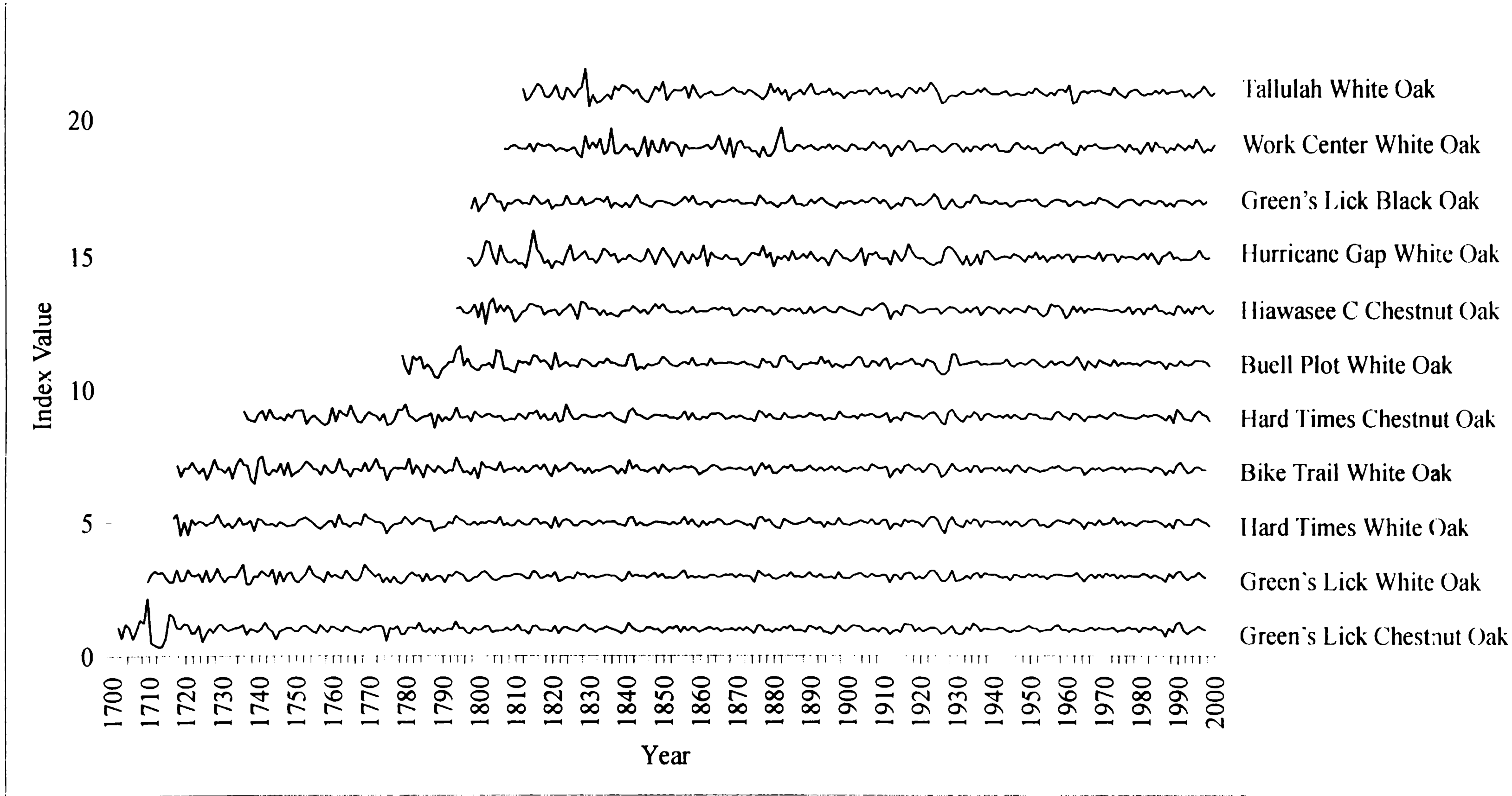


Figure 3-6. Site-species index chronologies (arranged in order of length), developed from all single-tree standardized index chronologies of a given species at the site.

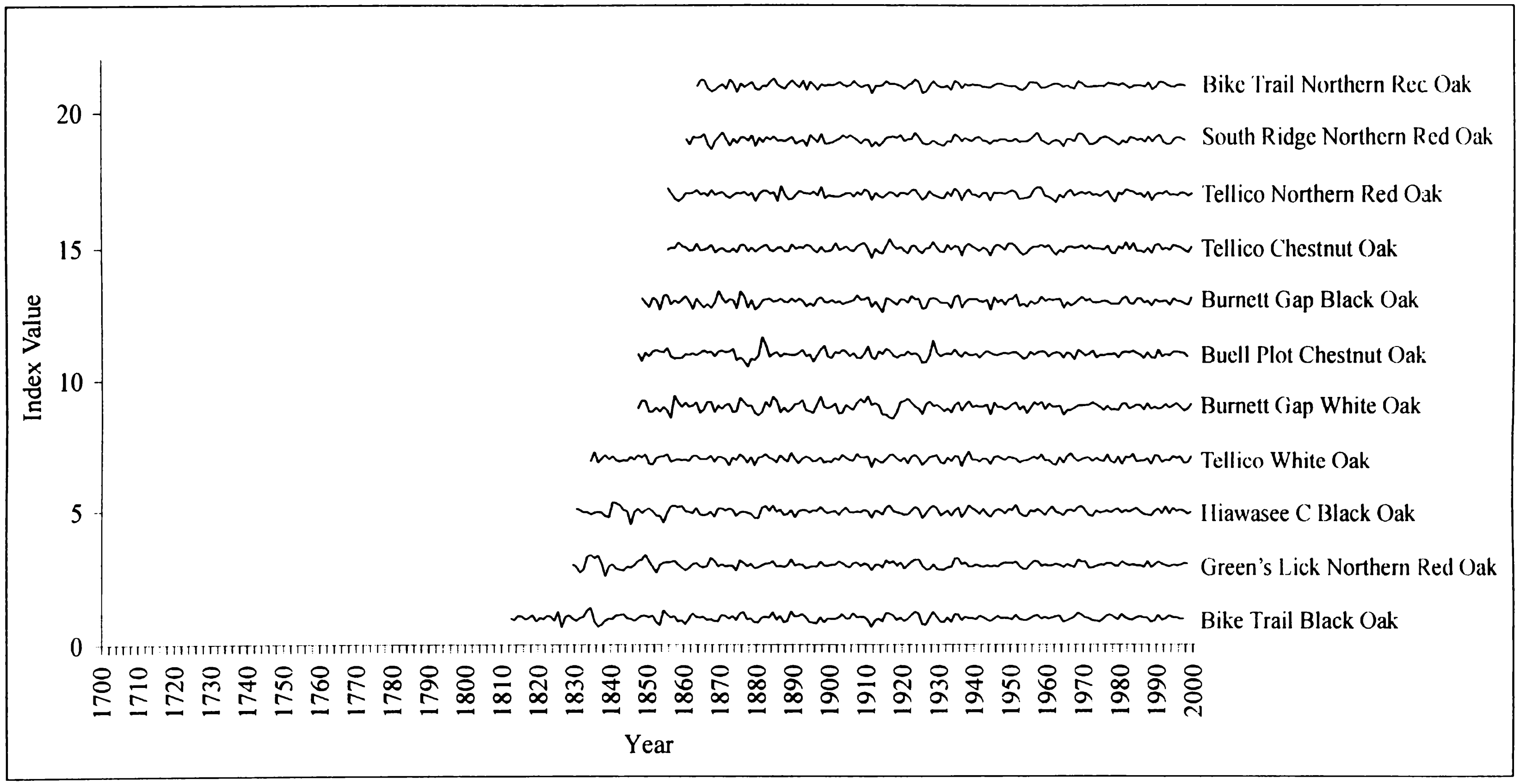
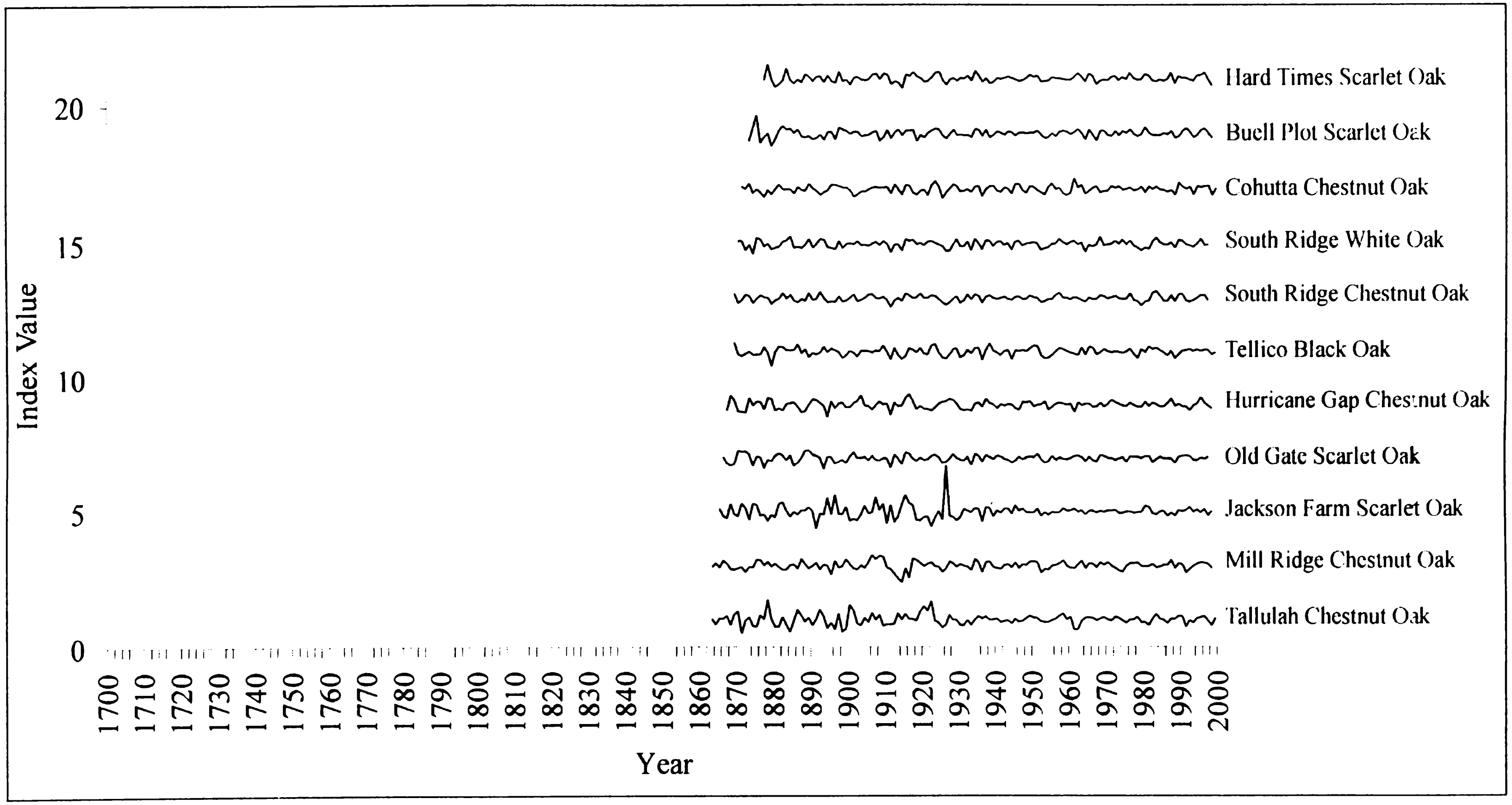


Figure 3-6 (continued).



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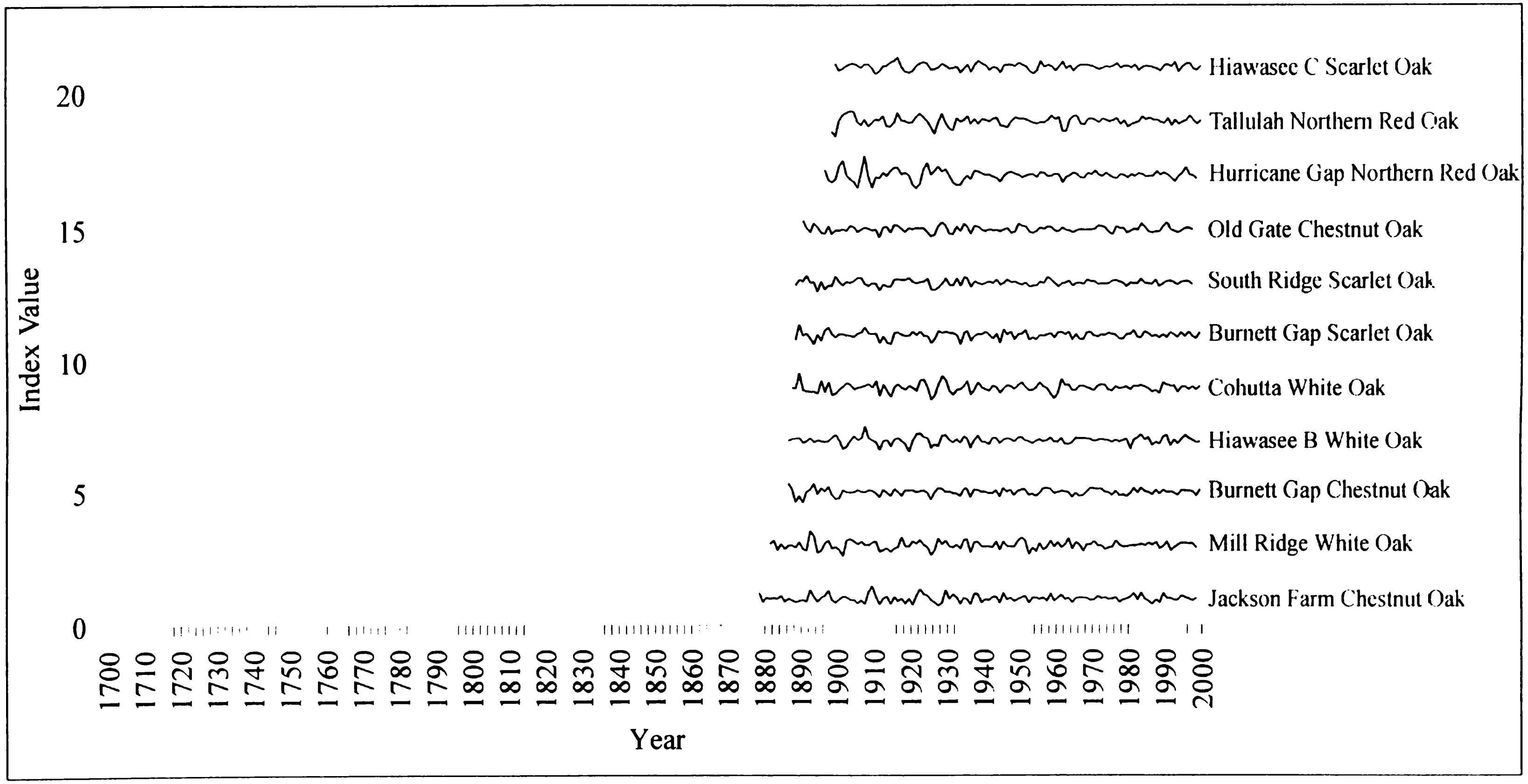

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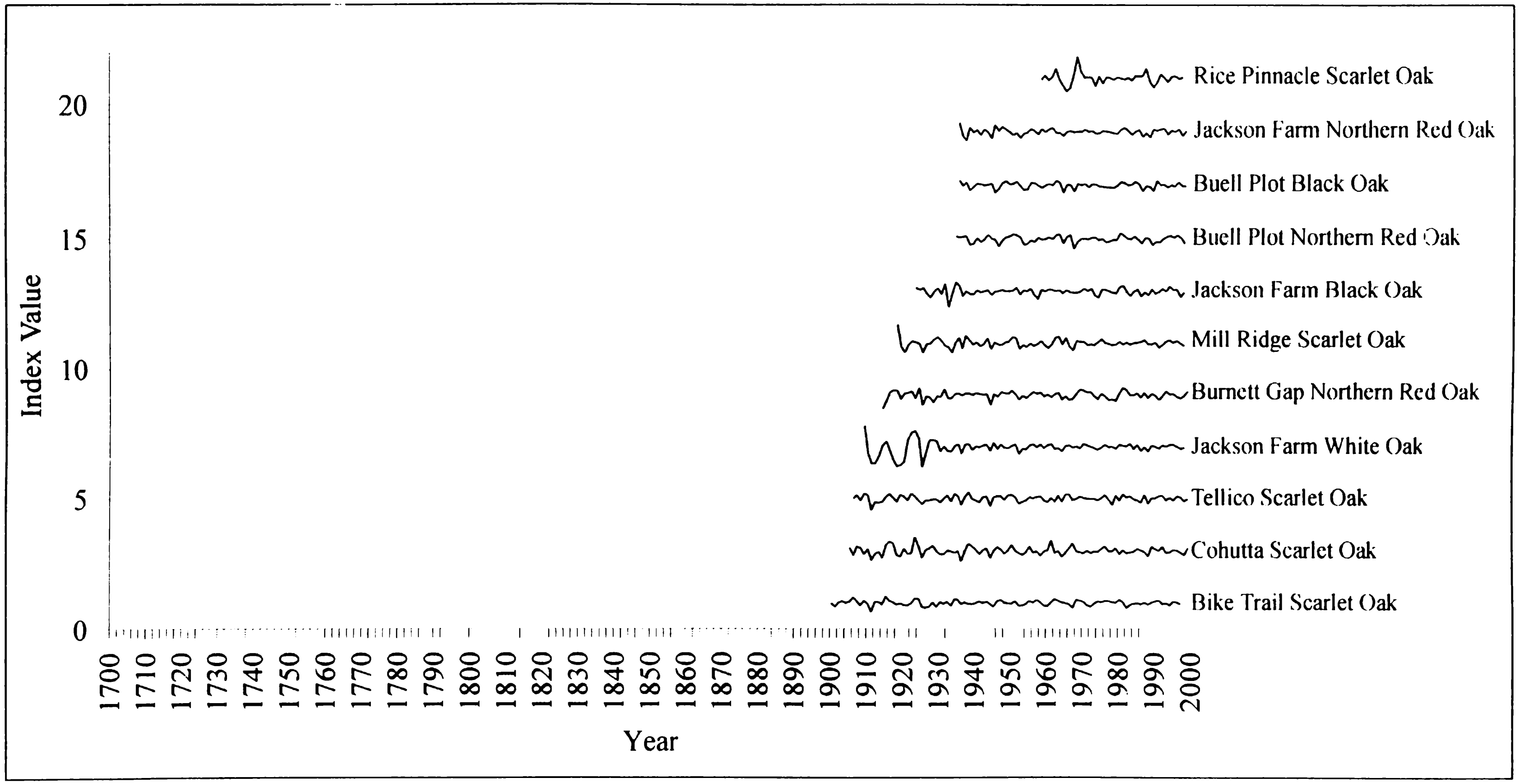

Figure 3-6 (continued).

Table 3-5. Statistics for the climate models developed with the regional species chronologies. The climate variables were created by averaging the Tennessee division 1 and North Carolina division 1 PDSI and Temperature variables. For the climate models, y is the tree-ring index value PDjun is PDSI June, PDjul is PDSI July, PDmayp is PDSI prior May, Tmayp is temperature from the prior may, and Tsep is temperature for the current September. We used these regional species chronology responses to determine the monthly climate variables to include in the climate models for the site-species climate analysis.

Species	*R*	*R2*	*D-W*	*p*	*Climate model*
Black Oak	0.607	0.369	1.470	0.000	y = 0.0259PDjun + 0.0084Tmayp - 0.0075Tsep + 0.961
Chestnut Oak	0.606	0.367	2.103	0.000	y = 0.0220PDjul - 0.0118PDmayp - 0.0077Tsep + 1.515
Northern Red Oak	0.477	0.228	1.571	0.000	y = 0.0121PDjun +0.0076Tmayp - 0.0077Tsep + 1.027
Scarlet Oak	0.514	0.264	1.993	0.000	y = 0.0176PDjul + 0.0062Tmayp - 0.0058Tsep + 0.987
White Oak	0.598	0.358	1.967	0.000	y = 0.0219PDjul - 0.0083Tsep + 0.0058Tmayp + 1.184

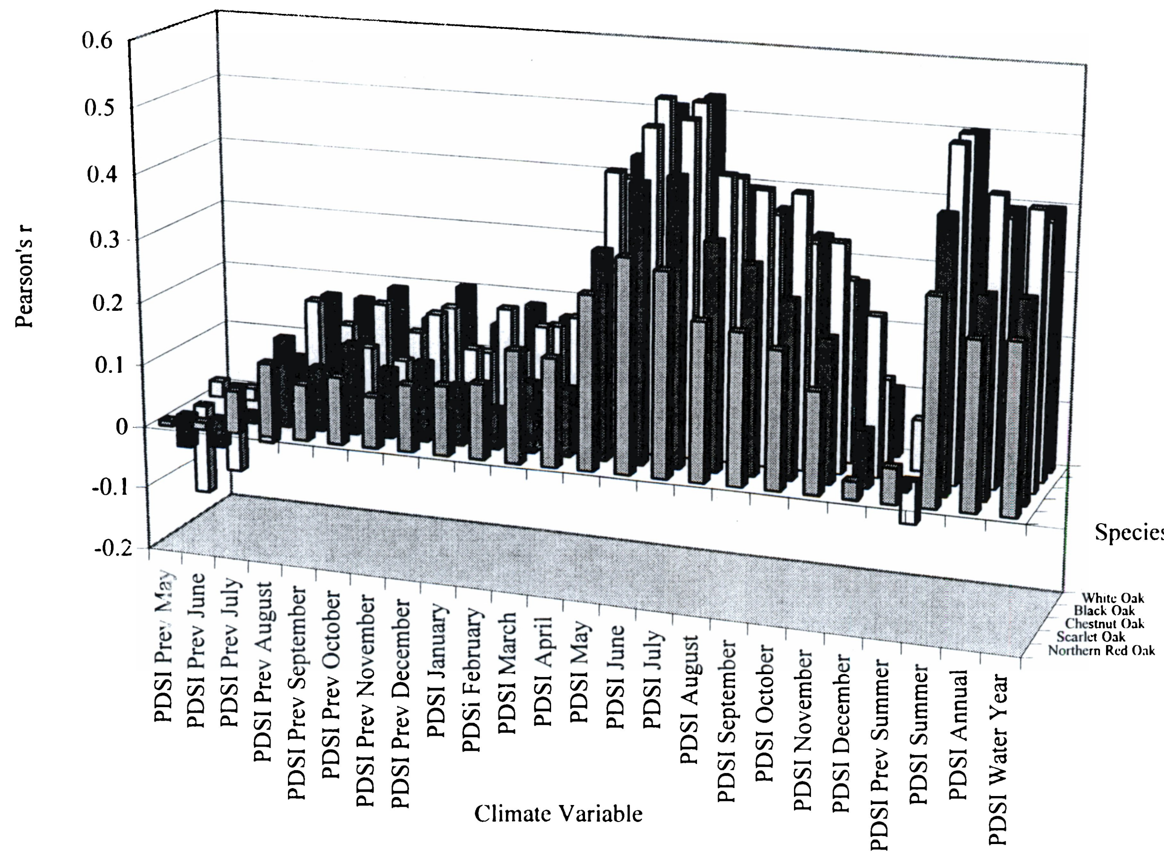

Figure 3-7. The response of the regional species chronologies to PDSI. Note that the tree-ring index chronologies are highly correlated with PDSI from the summer month a of the current growing season and also the annual and water year PDSI averages.

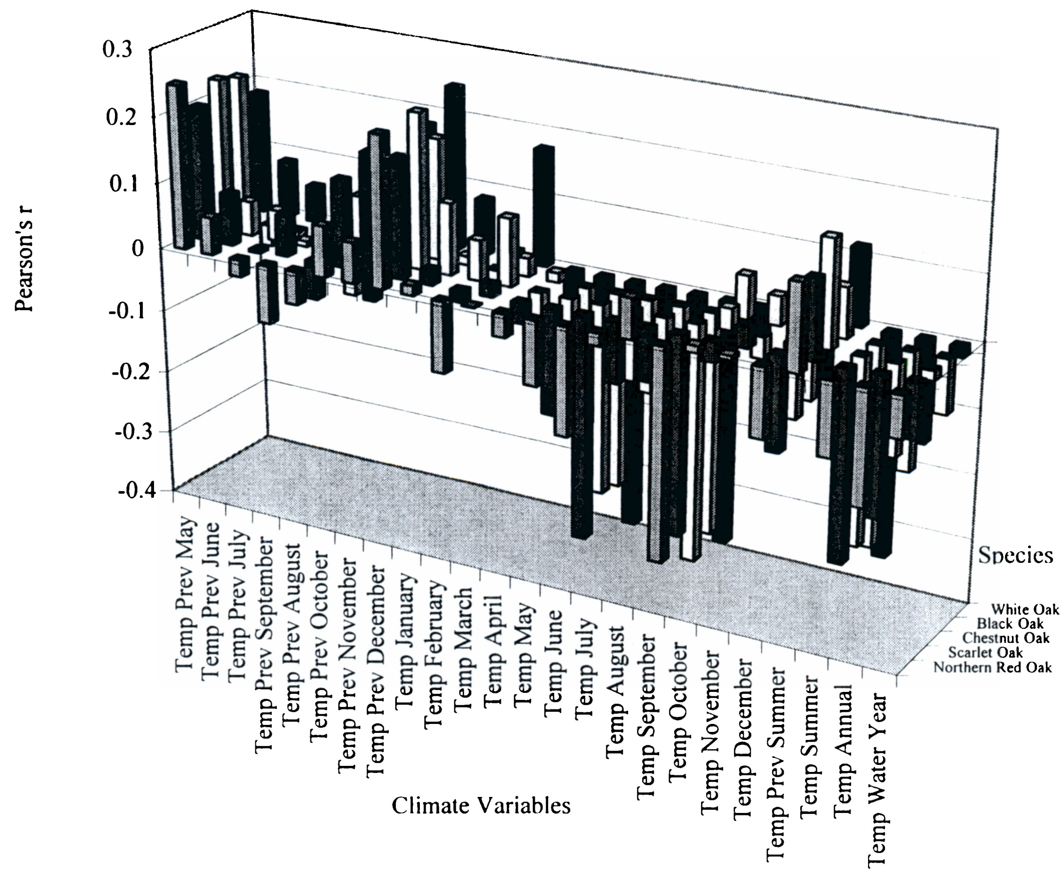

Figure 3-8. The response of the regional species chronologies to temperature. Note that the tree-ring index chronologies are highly correlated with temperature in September of the current year.

drought conditions. Regional chronologies of all five species showed very similar responses to climate. That some species respond better to June PDSI and others to July may be due to slightly different timing of growth in different species. Our climate models explained 37% of the variance in the regional black oak chronology and the regional chestnut oak chronology, 36% in the white oak chronology, 26% in the scarlet oak chronology, and 23% in the northern red oak chronology. All of the regional species chronologies have low autocorrelation (average D-W = 1.821) (Table 3-5).

For reasons discussed above, the climate parameters chosen for the regional species chronologies were imposed for each site-species chronology. The same three monthly climate variables were incorporated in the site-species regression models that had been included in the regional models for the same species. Results varied considerably: from 0.3% to 39.0% of site-species variance was explained in different cases (Table 3-6a-e). Significant climate models were developed for 71% of the chronologies ($p < 0.05$). Only one of the 55 site-species chronologies was highly autocorrelated (average D-W = 1.682).

Species compared

In the Bibliography of Dendrochronology (Grissino-Mayer 2001) we found nine published articles dealing with climate in the southeastern U.S. that mention white oak, five for northern red oak, four for black oak, and three each for scarlet and chestnut oak. Because white oak has been the most commonly used eastern North American oak species for climate reconstruction, we examined our results to see whether white oak was particularly suited for climate reconstruction using PDSI and temperature variables.

Table 3-6. The variance explained by PDSI and temperature in the a) black oak chronologies. The predictors for the climate model where June PDSI, previous May temperature, and September temperature. D-W is the Durbin Watson statistic measuring the amount of autocorrelation in the time series. The rows marked with a dash designate sites that did not have at least five of this species present and, therefore, no site-species chronology was developed.

Site	R^2	*p*	*D-W*
Bike Trail	0.158	0.001	1.554
Buell Plot	0.013	0.856	1.976
Burnett Gap	0.192	0.000	1.758
Cohutta	-	-	-
Green's Lick	0.178	0.000	1.242
Hard Times	-	-	-
Hiawassee B	-	-	-
Hiawassee C	0.270	0.000	1.605
Hurricane Gap	-	-	-
Jackson Farm	0.010	0.871	2.137
Mill Ridge	-	-	-
Old Gate	-	-	-
Rice Pinnacle	-	-	-
South Ridge	-	-	-
Tallulah	-	-	-
Tellico	0.392	0.000	1.468
Work Center	-	-	-
Minimum	0.010		1.242
Average	0.173		1.677
Maximum	0.392		2.137

Table 3-6 Continued. b) chestnut oak chronologies. The predictors for the climate model where July PDSI, previous May PDSI, and September temperature. D-W is the Durbin Watson statistic measuring the amount of autocorrelation in the time series. The rows marked with a dash designate sites that did not have at least five of this species present and, therefore, no site-species chronology was developed.

Site	R^2	p	***D-W***
Bike Trail	-	-	-
Buell Plot	0.073	0.056	1.910
Burnett Gap	0.143	0.001	1.712
Cohutta	0.294	0.000	1.667
Green's Lick	0.202	0.000	1.925
Hard Times	0.347	0.000	1.928
Hiawassee B	-	-	-
Hiawassee C	0.258	0.000	1.777
Hurricane Gap	0.083	0.034	1.615
Jackson Farm	0.104	0.012	1.826
Mill Ridge	0.067	0.075	1.274
Old Gate	0.235	0.000	1.853
Rice Pinnacle	-	-	-
South Ridge	0.205	0.000	1.529
Tallulah	0.049	0.182	1.539
Tellico	0.316	0.000	1.760
Work Center	-	-	-
Minimum	0.049		1.274
Average	0.183		1.717
Maximum	0.347		1.928

Table 3-6 Continued. c) northern red oak chronologies. The predictors for the climate model where June PDSI, previous May temperature, and September temperature. D-W is the Durbin Watson statistic measuring the amount of autocorrelation in the time series. The rows marked with a dash designate sites that did not have at least five of this species present and, therefore, no site-species chronology was developed.

Site	R^2	*p*	*D-W*
Bike Trail	0.117	0.007	1.617
Buell Plot	0.068	0.228	1.587
Burnett Gap	0.029	0.490	1.576
Green's Lick	0.115	0.007	1.442
Hard Times	-	-	-
Hiawassee B	-	-	-
Hiawassee C	-	-	-
Hurricane Gap	0.030	0.389	1.251
Jackson Farm	0.081	0.162	1.990
Mill Ridge	-	-	-
Old Gate	-	-	-
Rice Pinnacle	-	-	-
South Ridge	0.097	0.018	1.390
Tallulah	0.124	0.004	1.352
Tellico	0.249	0.000	1.442
Work Center	-	-	-
Minimum	0.029		1.251
Average	0.101		1.516
Maximum	0.249		1.990

Table 3-6 Continued. d) scarlet oak chronologies. The predictors for the climate model where July PDSI, previous May temperature, and September temperature. D-W is the Durbin Watson statistic measuring the amount of autocorrelation in the time series. The rows marked with a dash designate sites that did not have at least five of this species present and, therefore, no site-species chronology was developed.

Site	R^2	*p*	***D-W***
Bike Trail	0.032	0.385	1.737
Buell Plot	0.052	0.105	1.982
Burnett Gap	0.196	0.000	1.706
Cohutta	0.213	0.000	1.857
Green's Lick	-	-	-
Hard Times	0.133	0.003	1.720
Hiawassee B	-	-	-
Hiawassee C	0.126	0.004	1.419
Hurricane Gap	-	-	-
Jackson Farm	0.003	0.952	2.016
Mill Ridge	0.145	0.007	1.789
Old Gate	0.127	0.004	1.970
Rice Pinnacle	0.155	0.104	1.387
South Ridge	0.125	0.004	1.612
Tallulah	-	-	-
Tellico	0.318	0.000	1.836
Work Center	-	-	-
Minimum	0.003		1.387
Average	0.135		1.753
Maximum	0.318		2.016

Table 3-6 Continued. e) white oak chronologies. The predictors for the climate model where July PDSI, September temperature, and previous May temperature. D-W is the Durbin Watson statistic measuring the amount of autocorrelation in the time series. The rows marked with a dash designate sites that did not have at least five of this species present and, therefore, no site-species chronology was developed.

Site	R^2	*p*	***D-W***
Bike Trail	0.247	0.000	1.917
Buell Plot	0.173	0.000	1.759
Burnett Gap	0.057	0.116	1.396
Cohutta	0.350	0.000	1.597
Green's Lick	0.132	0.003	2.006
Hard Times	0.285	0.000	2.060
Hiawassee B	0.173	0.000	1.559
Hiawassee C	-	-	-
Hurricane Gap	0.058	0.112	1.759
Jackson Farm	0.044	0.272	1.043
Mill Ridge	0.119	0.005	1.941
Old Gate	-	-	-
Rice Pinnacle	0.070	0.459	1.513
South Ridge	0.155	0.001	2.043
Tallulah	0.114	0.007	1.476
Tellico	0.344	0.000	1.944
Work Center	0.234	0.000	1.594
Minimum	0.044		1.043
Average	0.170		1.707
Maximum	0.350		2.060

Based on our 55 site-species chronologies, white oak chronologies do not yield significantly higher series intercorrelations than the other four oak species studied ($p<.005$; Figure 3-1). However, the white oak chronologies do have a significantly higher mean sensitivity ($p<.005$; Table 3-3; Figure 3-2). Comparing all site-species chronologies, we found that chestnut oak correlated best with climate. Also, chestnut oak had more sites with relatively high amounts of variance explained by climate (average $r^2=0.183$, max $r^2=0.347$). Other species in order of average variance explained (Figure 3-9; Table 3-6) were white oak (average $r^2=0.170$, max $r^2=0.350$), black oak (average $r^2=0.153$, max $r^2=0.392$), scarlet oak (average $r^2=0.135$, max $r^2=0.318$), and northern red oak (average $r^2=0.101$, max $r^2=0.249$).

DISCUSSION

Based on their series intercorrelations and mean sensitivities, the oak chronologies developed in this study were statistically strong, suggesting that the trees respond to coherent regional- and stand-level controls. Our results compare favorably to series intercorrelations and mean sensitivities from other sites in the southeastern United States. Chronology statistics from 84 sites and 16 species demonstrate that the average series intercorrelation is 0.492 and the average mean sensitivity is 0.255 (Table 3-7). The chronology statistics from 48 other oak chronologies indicate an average series intercorrelation of 0.400 and the average mean sensitivity of 0.188. In comparison, our averages (0.564 and 0.195 respectively) are quite good for sites in mesic environments

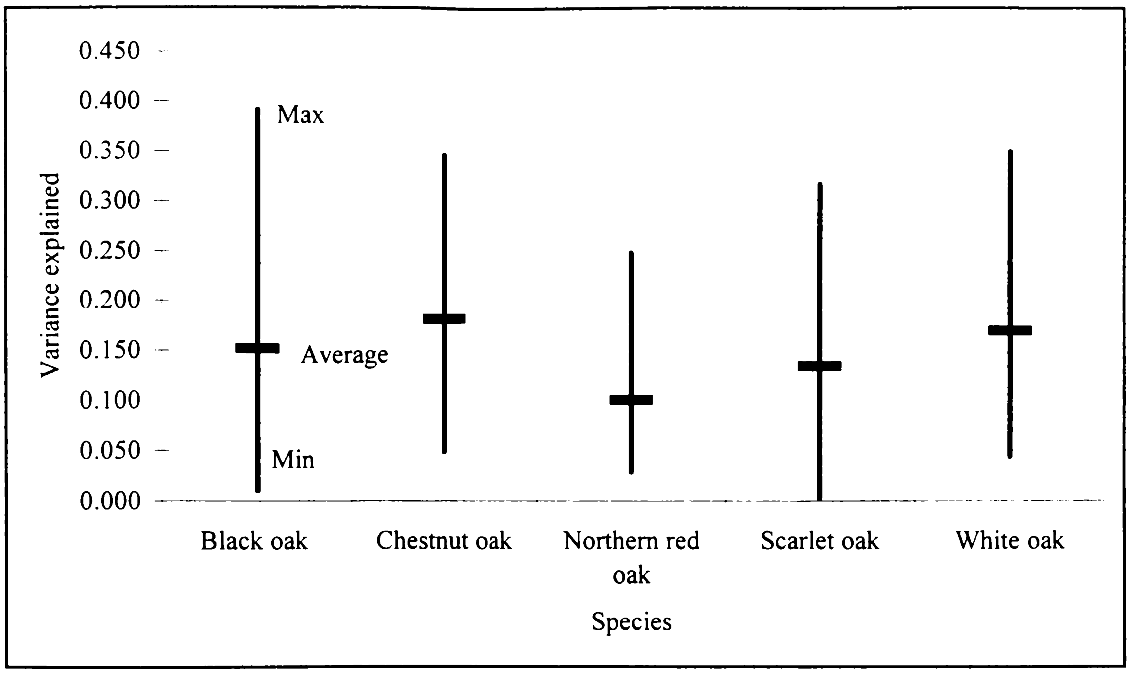

Figure 3-9. The proportion of variance explained for each site-species chronology by the PDSI models with variables chosen for each species at the regional level.

Table 3-7. Chronology statistics from 84 sites and 16 species developed in the southeastern United States compared to our results. The data source shows the published article from which these data were taken, or else ITRDB 2000, which means these values are reported on the internet for the holdings of the ITRDB.

Species	*Number of Sites*	*Series intercorr.*	*Average Mean Sensitivity*	*Location*	*Data Source*
Liriodendron tulipifera	1	0.650	0.365	Tennessee	ITRDB 2000
Picea rubens	2	0.550	0.199	North Carolina	ITRDB 2000
Pinus echinata	1	0.529	0.262	Georgia	ITRDB 2000
Pinus echinata	1	0.758	0.300	Tennessee	ITRDB 2000
Pinus echinata	2	0.417	0.247	North Carolina	ITRDB 2000
Pinus echinata	12	0.480	0.200	Southeastern U.S.	Estes 1970
Pinus palustris	3	0.497	0.279	North Carolina	ITRDB 2000
Pinus taeda	3	0.465	0.242	North Carolina	ITRDB 2000
Quercus alba	5	0.647	0.226	Tennessee	ITRDB 2000
Quercus alba	3	0.395	0.193	Southern Illinois	Robertson 1992
Quercus alba	3	0.524	0.202	North Carolina	ITRDB 2000
Quercus alba	4	0.491	0.142	South Carolina	Jacobi and Tainter 1988
Quercus alba	11	0.320	0.190	Southeastern U.S.	Estes 1970
Quercus lyrata	2	0.373	0.217	Southern Illinois	Robertson 1992
Quercus macrocarpa	1	0.256	0.194	Southern Illinois	Robertson 1992
Quercus michauxii	3	0.289	0.200	Southern Illinois	Robertson 1992
Quercus pagodaefolia	3	0.415	0.174	Southern Illinois	Robertson 1992
Quercus palustris	1	0.383	0.169	Southern Illinois	Robertson 1992
Quercus rubra	2	0.274	0.149	Southern Illinois	Robertson 1992
Quercus shumardii	1	0.447	0.191	Southern Illinois	Robertson 1992
Quercus velutina	9	0.380	0.200	Southeastern U.S.	Estes 1970
Taxodium distichum	1	0.633	0.504	Tennessee	ITRDB 2000
Taxodium distichum	2	0.655	0.576	North Carolina	ITRDB 2000
Taxodium distichum	3	0.662	0.594	Georgia	ITRDB 2000
Tsuga canadensis	1	0.623	0.247	Tennessee	ITRDB 2000
Tsuga canadensis	2	0.550	0.211	North Carolina	ITRDB 2000
Tsuga caroliniana	2	0.635	0.224	North Carolina	ITRDB 2000
Quercus alba	15	0.567	0.216	Southern Appalachians	This study
Quercus coccinea	12	0.583	0.181	Southern Appalachians	This study
Quercus prinus	14	0.543	0.195	Southern Appalachians	This study
Quercus rubra	10	0.520	0.190	Southern Appalachians	This study
Quercus velutina	7	0.605	0.191	Southern Appalachians	This study

with closed canopies. Also, our trees had been chosen for a mast study and neither sites nor individuals were selected for climate analysis. These factors, combined with the significant amount of variance explained by PDSI and temperature, suggest that climate is a strong stand-level signal that affects tree growth in this region.

White oak is frequently used for climate reconstructions in eastern North America. Our results show that white oak does not, on average, record a stronger stand-level climate signal than the other four oak species studied, although its higher mean sensitivity may indicate that it is better able to record climate variability. The stronger climate response found in the chestnut oak chronologies suggests that chestnut oak should be used more often for climate reconstruction purposes. Scarlet oak and black oak also demonstrated good chronology statistics and high correlations with precipitation, temperature, and PDSI. Therefore, more work can be done using all three of these species (chestnut, black, and scarlet oak) for future climate reconstructions. Our results show that northern red oak has the weakest chronology statistics of the five species in our study and does not record climate well on most sites.

Because this study is part of a larger project on mast reconstruction, we used a liberal standardization method (a 15-year cubic smoothing spline) to remove signals that were considered to be noise. We would have used a different approach if our primary goal had been to reconstruct climate including longer-term patterns. Our approach probably enhanced interannual variability and thereby artificially increased statistical response to short-term climatic variability while obscuring chronology relationships to long-term climate patterns.

In future studies we recommend that chestnut oak, scarlet oak, and black oak be used as well as white oak for climate reconstruction. Finally, our results demonstrate that sites in closed canopy oak forests can be useful for climate reconstruction and should be utilized when circumstances warrant.

Chapter 4

Mast Reconstruction in Southern Appalachian Oaks and the Implications for Carbon Allocation

INTRODUCTION

Masting is intermittent heavy fruiting by a population of plants. An extreme mast event occurs when the majority of a given species in a region produce a large amount of fruit in one year. Masting behaviors can be subdivided into three levels that describe how completely a population masts. These levels are: (1) "putative," in which fluctuations in masting are simply due to resource matching (better growth conditions result in more fruit); (2) "normal" masting, in which the amount of fruit produced each year is highly variable and somewhat synchronous; and (3) "strict" masting, in which fruiting is bimodal with very few intermediate mast years (Kelly 1994). Putative masting produces a pattern of fruit production that can be highly variable but does not result in much of a strain on the plants' resources because the plants simply use current growing conditions to produce a large crop. Strict masting represents the other extreme, in which either a large crop is produced or virtually no fruit are produced in any given year.

Koenig and Knops (2000) found normal masting to be the most likely type of masting exhibited in most North American tree genera, including oaks. Normal masting occurs when the trees either switch resources from growth to reproduction or accumulate resources during non-mast years. Resource accumulation would require an intermediate period between heavy mast events while resources are stored before subsequent good mast years can occur. Resource accumulation would not result in a trade-off between incremental growth and reproductive effort, whereas resource switching would result in such a trade-off because the resources to produce fruit must come directly from that year's growth. Normal masting associated with resource switching should produce a distinct signal in tree rings. If a good mast year deprives the tree of resources, a narrow tree ring will result the years that the fruit are developing. A poor mast year should allow uninhibited incremental growth so that another limiting factor predominates.

Foresters have been studying acorn production because it is important for wildlife management as well as for oak ecology. Hard mast (acorns and other nuts) is an important food source for game species in the southeastern United States, especially during late summer and fall. Long-term records of mast could provide information about the temporal dynamics of acorn production and could potentially answer many questions in oak ecology and wildlife management. Masting is extremely episodic and researchers have been investigating the driving mechanisms behind mast events to better understand and hopefully predict fluctuations in mast production. Researchers are handicapped by the short length of reliable masting records. Reconstructed masting history would provide the data needed to explore long-term mast dynamics. If reliable methods for mast reconstruction can be established, then long-term mast records can be developed that span the lifetime of the trees, or even longer where sources of undecayed deadwood can be found.

Biology of masting

Two main groups of hypotheses have been proposed to explain the existence of masting in tree species. The first group proposes that masting is simply the product of resource matching, *i.e.* the trees merely respond to the current growing conditions. In this case, favorable climate would result in a large crop and possibly a large amount of incremental growth. The other group of hypotheses suggests that masting is an evolved strategy that has arisen through natural selection as a result of economies of scale. The two main hypotheses in this group maintain that (1) masting is selected for by causing seed predator satiation (Silvertown 1980) and (2) that masting is selected for by improving wind pollination success (Smith *et al.* 1990). In either case, trees that flower and produce fruit synchronously would have an ecological advantage.

Sork *et al.* (1993) believe they found evidence of cycles in the masting of oak trees in three different species that grow in the eastern deciduous forest. They infer that black oak (*Quercus velutina* Lam.) has a 2-year cycle, white oak (*Q. alba* L.) has a 3-year cycle, and red oak (*Q. rubra* L.) has a 4-year cycle. They further suggest that these cycles are the result of an evolved strategy in which it is necessary to use previously stored reserves to successfully produce a large crop of acorns. They hypothesize that resource accumulation within the tree may trigger a mast event once the resources reach a certain level. Such a mechanism supports the evolved strategies hypothesis, but because of the necessity of resource accumulation, the current year's ring width would not necessarily be reduced.

Sork *et al.* (1993) postulate that this inferred periodic masting behavior continues only until reset by climate stresses, and therefore does not produce cyclic behavior that is stable through time. In their eight year study, 55% to 89% of the variance in mean annual mature acorn crop size was explained by principle components derived from climatic variables, especially spring climate. Sharp and Sprague (1967) similarly found that warm weather in spring significantly affected white oak acorn crops in the fall of the same year. They showed that good acorn crops were produced in five out of 14 years when April nighttime temperature was unseasonably warm, although May was cooler than average. The eight years of the study with poor acorn crops were, on average, 7.2°C cooler in day and nighttime temperatures for the period of April 20-29. Sharp and Sprague (1967) found that difference in temperature (not freezing temperatures or drought) affected their acorn crops. These studies suggest that, although the evolved strategies hypothesis may be the dominant driving mechanism of mast, climate still has an effect even though resource matching only plays a secondary role.

These hypotheses can be tested by determining the effect that heavy mast years have on annual ring width. Furthermore, if mast reconstructions can be developed for the lifetime of the trees, we would have the temporal depth to be able to test masting patterns against climate records for 100 years or more. The first part of this analysis depends upon the premise that a tradeoff exists between incremental growth and reproductive effort.

Tree-ring biology

Mast data have not previously been compared to tree rings in oaks to see if a heavy acorn crop produces reduced radial growth that year. Furthermore, no published report has attempted to reconstruct mast from tree-ring data for any genus. In this study, we report the results of dendrochronological reconstruction of mast in oak trees. Methods for reconstructing mast events follow the same basic technique used to reconstruct other short-term stresses on tree growth (such as insect outbreaks), and is based on the Linear Aggregate Growth Model (Graybill 1982; Cook 1985). This is a conceptual model that defines factors that affect tree growth (Equation II).

$$R_t = A_t + C_t + \delta D_{1t} + \delta D_{2t} + E_t \qquad \text{[II]}$$

where R_t is the ring width in year t, A_t is the age-related growth trend; C_t, the climate; D_{1t}, the effects of endogenous disturbances; D_{2t}, the effects of exogenous disturbances; and E_t, the residual error. δ is a binary function with a value of 1 if the disturbance is present in year t and 0 if it is not. In this conceptual model, exogenous and endogenous disturbances can represent many concurrent disturbances to tree growth.

The age-related growth trend and climate are usually the dominant signals recorded in ring width. Standardization techniques (*e.g.,* the use of a flexible cubic-smoothing spline) are used to remove age-related growth trends. This trend is purely a geometric artifact of tree growth, because the tree lays down a thin layer of wood on an ever-increasing cone. With the same amount of wood produced each year, the ring width will gradually decrease because of the larger surface area that the wood has to cover. In an ideal situation, this age-related growth trend can be removed with a simple negative-exponential curve, but when competition with other trees (especially for light) is taken into consideration, the growth related noise becomes much more complex. The flexible cubic-smoothing spline is able to remove this complex pattern of releases and suppressions as well as the long-term age-related growth trend (Cook and Peters 1981).

Standardization mainly removes long-term trends like the age-related growth trend, but a flexible spline like the one that we are using will remove some low frequency climate signals on the order of a decade or greater. To remove short-term climate we can conduct a climate subtraction. By using dendroclimatic reconstruction methods to identify and remove short-term climate signals, we seek to develop tree-ring chronologies in which an enhanced signal of masting dominates the remaining record.

Similar methods have proven useful for reconstructing insect outbreaks once individual tree variability is averaged into stand-level chronologies. In contrast, the masting signal may be strongest at the single-tree level because this is the scale at which resource tradeoff occurs. Competition between trees for light, water, and nutrients may also strongly affect annual growth of individual trees. Most often, such confounding factors are removed by averaging chronologies from many trees in a stand. In this study we examine regional, stand, and tree-level chronologies for evidence of a mast signal. We examine individual tree chronologies to see how their own masting affects their growth, recognizing that noise from competition may be overwhelming at this level.

A reduction in ring width due to masting has been recorded in many genera such as beech (*Fagus*), *Psuedotsuga*, fir (*Abies*), pine (*Pinus*), and spruce (*Picea*) (Holmsgaard

1958; Eis *et al.* 1965). Estimates of the biomass incorporated in mast production in beech trees reach as high as 139% of leaf biomass production and 70% of annual wood-mass production (Nielson 1977). This large drain on the resources of the tree has been documented as a reduction of wood volume the year(s) fruit is on the tree. Heavy mast events in beech trees were found to cause at least 40% growth suppression (Holmsgaard 1958). Eis *et al.* (1965) examined ring-width data in conjunction with cone count records for a 28-year period, and found that heavy mast events in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), and western white pine (*Pinus monticola* Dougl. ex D. Don in Lamb.) result in reduced growth the year(s) the cones are on the tree: one year in Douglas-fir and grand fir, two in western white pine.

Because the trees expend a large amount of energy producing fruit during heavy mast years, and because heavy mast events have been shown to reduce ring widths in many tree genera, we hypothesized that a good mast year will produce a reduced ring width the years that the acorns are developing on oak trees. In this paper, we report results supporting that hypothesis, and our attempt to reconstruct mast history based on those results.

METHODS

Site description

Greenberg (2000) has been collecting mast information using 0.5 m diameter acorn traps under 931 individual oak trees on 17 sites in the southern Appalachians (Figure 2-1). We cored the trees in her study to develop ring-width series on trees with modern tree-level mast records. Three sites are located in the Chattahoochee National Forest of northern Georgia: Cohutta, Tallulah, and the Forest Service Work Center outside of Brasstown. Five sites are located in the Cherokee National Forest of eastern Tennessee: Burnett Gap, Hiawassee B, Hiawassee C, Jackson Farm, and Tellico. Nine sites are located in the Pisgah National Forest of western North Carolina, seven of which are in the Bent Creek Experiment Forest: Buell Plot, Bike Trail, Green's Lick, Hard Times, Old Gate, Rice Pinnacle, and South Ridge; the two remaining sites are located closer to the border with Tennessee: Hurricane Gap and Mill Ridge (Table 4-1; Figure 1-2).

Most of our sample sites are located between 400 and 800 m elevation, with our lowest site at 270 m and our highest at 1149 m (Table 4-1; Figure 1-2). All of the sites are situated in the varied topography of the southern Appalachians in the Eastern Deciduous Forest Province, Appalachian Oak Forest Section (Bailey 1980). This forest type has various oak species as the dominant tree type with beech, basswood, hickory, hemlock, pine, and yellow poplar also present. Each of our sample sites contains up to five oak species: white oak *(Quercus alba* L.), chestnut oak *(Q. prinus* L.), northern red oak *(Q. rubra* L.), black oak *(Q. velutina* Lam.), and scarlet oak *(Q. coccinea* Muenchh.). Mast traps were installed under the drip lines of the trees between 1991 and 1993. These trees were tagged and their locations mapped. The Forest Service also recorded the species, diameter at breast height (DBH), crown class, crown size, slope, aspect, terrain shape index (TSI), and landform index (LFI) of each tree (Table 4-1). Trees werc selected to represent a variety of ages and landscape positions so that the pertinent factors that drive good mast production could be investigated. This variety also enabled us to examine how these characteristics affect the ability of a tree or site to record mast.

Mast data

We used two different mast data sets for our analysis, the site-specific U.S. Forest Service (USFS) data set obtained as described above, and a broader-scale State Wildlife Resources Agencies (SWRA) data set. The two sets have different qualities that allowed us to test different aspects of tree growth response to masting. USFS data consist of actual acorn counts and are reported at the individual tree level, providing the opportunity to aggregate to higher levels. Six years of mast data were available when we sampled the trees. We benefited from this tree-level data but our statistical analyses were hindered by the short temporal record. The SWRA ranked observations on an ordinal scale of one to ten for each year, with ten being a heavy mast year. These data are only at the stand or county level, but extend up to 24 years in length, providing a longer time series for more robust regression analyses.

Table 4-1. Site characteristics. Elevations in meters. Slope Position: L, M, U = low, middle, upper; R = ridge. For a description of TSI and LFI see McNab (1989).

Site ID	*Average Elevation*	*Slope Position*	*Aspect (Azimuth)*	*Percent Slope*	*Slope Severity*	*Terrain Shape Index (TSI, local)*	*Qualitative Terrain Shape*	*Landform Index (LFI, General)*	*Qualitative Landform*
Cohutta	441	M	30 (ENE)	25	Steep	0.067	Side Slope	0.229	Cove
Tallulah	606	M	345 (NNW)	35	Very Steep	0.047	Side Slope	0.309	Cove
Work Center	755	U	210 (SSW)	14	Moderate	0.050	Side Slope	0.146	Ridge
Hiawassee C	481	U	330 (NNW)	15	Moderate	0.084	Cove	0.116	Ridge
Hiawassee B	270	M	180 (S)	22	Steep	0.094	Cove	0.217	Cove
Burnett Gap	644	M - R	330 (NNW)	20	Moderate	0.065	Side Slope	0.185	Ridge
Tellico	587	M	315 (NW)	18	Moderate	0.042	Side Slope	0.178	Ridge
Jackson Farm	481	M - U	60 (ENE)	10	Shallow	-0.024	Side Slope	0.132	Ridge
Buell Plot	695	M - U	360 (N)	22	Steep	0.005	Side Slope	0.151	Ridge
Bike Trail	729	L - M	30 (NNE)	23	Steep	-0.008	Side Slope	0.216	Cove
Green's Lick	910	L - R	75 (ENE)	30	Very Steep	-0.008	Side Slope	0.255	Cove
Hard Times	785	M	330 (NNW)	16	Moderate	0.069	Side Slope	0.110	Ridge
Old Gate	719	L - R	165 (SSE)	17	Moderate	0.008	Side Slope	0.154	Ridge
Rice Pinnacle	682	U	165 (SSE)	15	Moderate	0.015	Side Slope	0.135	Ridge
South Ridge	828	M	105 (ESE)	34	Very Steep	0.001	Side Slope	0.248	Cove
Hurricane Gap	1149	M	240 (WSW)	13	Moderate	0.059	Side Slope	0.117	Ridge
Mill Ridge	732	M - R	180 (S)	15	Moderate	0.014	Side Slope	0.139	Ridge

United Stated Forest Service (USFS) mast data

USFS data covering the years 1993 through 1998 are used in this paper. Because these data are at the individual tree level, we can compare the mast from an individual tree to that tree's annual growth increment. We were able to relocate 760 individual trees in this study. From two to 14 mast traps had been established under each tree, the number of traps approximately proportional to basal area of the tree. The traps were constructed of shade cloth attached to a metal ring 0.5m in diameter and attached to treated wood stakes or rebar ~1m above ground level (Figure 2-1). Because the traps do not collect acorns that are removed by arboreal consumers or occasionally stolen from the mast traps by other seed predators, the number of acorns recorded is considered a conservative estimate. The mast traps were positioned under the canopy of the sample trees with care taken to avoid the drip line of other oak trees. The traps, therefore, only collect acorns that fall from the sample tree. The acorns in the traps were collected approximately every two weeks throughout the fall. The acorns were taken back to the laboratory and counted. That count was extrapolated to the whole tree by multiplying by the ratio of total crown area to trap area. The number of acorns produced per tree each year were then reported (Greenberg 2000).

State Wildlife Resources Agency (SWRA) mast data

The SWRA of Georgia, Tennessee, and North Carolina have been collecting mast data at the stand level for up to 24 years. In each state, the data were collected by foresters who walked designated transects during the fall of the year and counted the number of acorns on randomly selected trees, using binoculars, every 100 meters along the transect (Whitehead 1969). These data were then converted to a ranking of the relative abundance of mast for that year, with one representing a mast failure and ten representing an extreme mast event. In Georgia, SWRA assessed approximately 600 trees each year over the past 21 years in counties from which we also have tree-ring samples. North Carolina has been collecting mast data on approximately 1000 oak trees in our study area for the past 16 years. Tennessee has been collecting data from 300 trees for the past 24 years.

The data from Georgia were reported at the transect level, and we averaged the data from multiple nearby transects to compare with our tree-ring data. Tree rings from the Cohutta site were compared to mast data from two transects (Watson Gap and West Cow Pen) within 10 miles of the site. On average, 245 oak trees were assessed each year on these two transects combined. Tree rings from the Brasstown Work Center site were compared to the Cooper's Creek WMA mast transect approximately 10 miles distant. On average, 86 oak trees were assessed each year. We compared our Tallulah site to mast data from four transects (Patterson Gap, Coleman River, Lake Burton highway, and Warwoman) within 20 miles of the sampled trees. On average, 268 oak trees were assessed between the four transects.

The data from North Carolina were reported on the division level; we used data from the western North Carolina division, where our tree-ring sites are located. Ten standard transects were walked in eight different counties with approximately 400 trees in the white oak group and 600 trees in the red oak group assessed each year.

The data from Tennessee were reported at the county level. Our six tree-ring sites are located within or on the borders of counties with mast data. Each year an average of 33 trees in the white oak group were assessed and an average of 28 trees in the red oak group were assessed along established transects in each county.

Field methods

We attempted to relocate all 931 trees in the Forest Service mast study, using the maps developed by the Forest Service technicians and the tree identification numbers. Poor road conditions prevented us from reaching one site, and a few individual trees could not be found, but we successfully located and cored 845 trees on the 17 sites.

We took two cores parallel to contour at breast height from each living tree and one core per dead tree. We sampled about half of the trees by hand and the other half using a power borer. The power borer is a Stihl chainsaw head fitted with an Atom drilling attachment. It was effective in quickly taking cores from the very hard oak trees. Using the power borer necessitated coring the trees at waist height because the chainsaw head had to be braced to prevent it from rotating. Once we took the cores, we stored them in plastic straws that we labeled with the site name and tree number. This information enabled us to refer back to the Forest Service database for the trees, containing the mast information as well as the tree and site characteristics.

Laboratory methods

We dried the cores, mounted them in wooden core mounts, and progressively surfaced them with a belt sander using 120-, 220-, 320-, and 400-grit sandpaper. After examination under the microscope, cores that still needed a better surface were hand-sanded with 320-grit sandpaper followed by 30 µm sanding film. The sanding film is a more uniform abrasive system so that a 30 µm sanding film is superior to an 850- grit sandpaper. The final surface was clear of scratches making the cell and ring structure readily visible under a 10- to 40-power stereozoom microscope.

We developed single-tree chronologies and separate site-level chronologies for each species sampled. A robust site-level chronology requires at least five trees so that individual tree variance does not control the stand-level chronology. Therefore, we only retained the species chronologies that had at least five trees contributing. We developed 55 chronologies from a total of 17 sites: 15 white oak, 13 chestnut oak, 12 scarlet oak, nine northern red oak, and six black oak. On average, 12 trees (range = 5 to 24) were included in each site-species chronology, with a total of 664 trees contributing to the complete data set.

We used skeleton plots (Stokes and Smiley 1968) from 10 cores at each site to develop a master dating chronology. We then used the marker rings from the master dating chronology to date the remaining samples (Douglass 1941). Finally, we measured all dated cores to 0.01mm precision using a Velmex measuring system.

The measured ring-width series were entered into the program COFECHA to assess the quality of crossdating (Holmes 1983). COFECHA takes each measured series and applies a 32-year cubic smoothing spline to remove the age-related growth trend and to enhance interannual variability. COFECHA then conducts autoregressive modeling to further enhance the high-frequency variability desirable in crossdating. Afterward it creates an index series for each core that is then averaged to create a master dating chronology. Once the master chronology exists, COFECHA tests the crossdating of each series by first removing them one at a time from the master chronology and comparing successive 50-year segments (with 25 years of overlap) to the master chronology using correlation analysis. COFECHA reports the best statistical fit for each 50-year segment, flagging any segments that match the master chronology in a position other than the dated position. In such a case, or if the current match had a low correlation, we rechecked the dating manually. We continued in this fashion until COFECHA and our analysis of the wood determined that all cores were accurately dated in each site-species chronology.

We then used the program ARSTAN to standardize all series (Cook 1985). The ARSTAN program produces single-tree chronologies by creating and averaging indices from the two cores per tree. The indices are calculated by subtracting a standardization curve from the actual measured ring width and then dividing by the standardization curve (Equation III).

$$Z_t = (RW_t - Y_t) / Y_t \quad \text{[III]}$$

where Z_t is the index value at time t, RW_t is the ring width, and Y_t is the value of the standardization curve. The tree-level chronologies were then averaged together to develop a stand-level chronology that was free of individual tree variations.

We standardized the cores using a 15-year cubic smoothing spline to remove low-frequency variations due to age-related growth trends, competition, disturbance, and climate so that the mast cycle would be enhanced. The 15-year spline leaves 50% of the variance at 15 years and leaves 99% of the variance at 5 years and less. Therefore, confounding factors with a 5-year or longer period will be dampened or removed from the chronology while retaining the interannual variation that may be due to masting.

Index chronologies

The most basic data in this study are the tree-level chronologies produced by ARSTAN. We compared these single-tree chronologies, using simple linear regression, to the USFS mast data from 1993-1998. We also used the USFS data to test each stand level site-species group to see which species record mast and at which sites. Still using the tree-level data, we tested all of the trees in one site-species group so that the sample size was 30–144 points; that is six points for each tree with a minimum of five trees in each site-species group. We found that the stand-level data were not normally distributed because of the high number of zero values (representing no acorns collected beneath a particular tree's canopy in a given year). For the purposes of regression analysis, we needed to transform the data so that it was normally distributed, so we censored the data, removing any zero values, and took the natural log of the remaining values.

We used the site description data collected by the Forest Service (elevation, percent slope, aspect, terrain shape index, and landform index) to determine which landscape characteristics might affect the tendency of a site to record mast. The terrain shape index (TSI) is a quantitative expression of the geometric shape of the local land surface (McNab 1989). The landform index (LFI) is a similar parameter, but it measures the geometric shape of the more general landscape by considering the visible horizon open to any given tree. We separated the sites into two populations, those that were sensitive to mast (*i.e.* correlated significantly) and those that were not. We then used a set of t-tests to compare the landscape characteristics between these two populations.

For both the tree- and stand-level analyses using the USFS mast data, we used the tree-ring indices without subtracting the effects of climate. We wanted to take advantage of the tree-level mast data because we know that this mast production was a strain on the resources of the individual trees that we were analyzing, and because climate analysis at the individual-tree level has many more problems than at the stand level. The climate pattern in tree rings is a good example of an emergent property (see Allen and Starr (1982) for a discussion of emergent properties and scale dynamics). We know that the individual trees are being affected by the climate they experience, but tree growth is also affected by local disturbances such as competition for light, nutrients, and soil moisture, so that the climate signal from individual trees is overwhelmed by the noise from these local disturbances. If, however, the tree-ring series are combined from 10 trees on a site, the individual tree noise cancels out and a stand-level climate signal remains.

Climate control

We tested the effectiveness of first removing climate from the tree-ring chronologies and then comparing the residual chronologies to mast data using the longer

SWRA mast data sets. We used Palmer Drought Severity Index (PDSI) and temperature from two local NOAA climate divisions (Tennessee 1 and North Carolina 1) as our climate control. We used all twelve current-year monthly values of PDSI, two annual means, two seasonal proxies, and also the eight lagged months of May through December of the previous year. We then determined the climate response of each of the 55 site-species chronologies using stepwise multiple regression. This climate analysis is reported in greater detail in chapter 3. We then used simple linear regression to compare the tree-ring residual chronologies to the SWRA stand-level mast data. We determined the amount of variance explained by climate and how much of the remaining variance was explained by mast in each of the site-species chronologies. Unless otherwise stated, we used a significance cutoff value of $p < 0.1$.

Mast reconstruction

For cases in which the relationship between the mast data and a site-species chronology was significant, we used the regression equation to generate a mast reconstruction for the length of the chronology. Using the residual ring-width chronology after climate removal as the independent variable, we used the equation to estimate the number of acorns produced per site for each year in the chronology. We calculated the Z-score for the reconstructed mast chronology (Equation IV).

$$Z_t = (X_t - \bar{X}) / s \qquad \text{[IV]}$$

where Z is the standardized value of the mast year, X is the reconstructed mast ranking, X bar is the mean of the reconstructed mast chronology, and s in the standard deviation of the reconstructed mast chronology. By plotting the Z scores and the 80% confidence intervals we identified the historical years estimated to have been significantly good (or bad) mast years.

The process of growth/reproduction tradeoff, carbon allocation, and carbon storage is not well understood in oak trees. Sork *et al.* (1993), however, suggest that a tree may store energy in preparation for a good mast year rather than applying that energy to growth. This should result in previous years' growth (after accounting for climate) being negatively correlated with the current year's mast data. Furthermore, if a tree exhausts its energy reserves to produce a heavy mast event, it is possible that subsequent years would show unusually narrow rings until reserves are replenished. To test these hypotheses, we used a correlation matrix to compare lagged tree growth (from –10 years to +5 years) against the SWRA mast data. We ran these tests only on chronologies that correlated significantly to mast at year zero.

RESULTS

Dating quality

The average series intercorrelation for all site-species chronologies in this study was 0.559 (ranges from 0.446 to 0.693) (Figure 3-1) and the average mean sensitivity was 0.196 (ranges from 0.140 to 0.266) (Figure 3-2, Table 3-3). Our series intercorrelation for each species is above the average of chronologies developed from other genera and species in the southeastern United States. Although our mean sensitivity is below the Southeastern average, it still shows that our chronologies are moderately sensitive to a variable climate (Table 3-7).

Mast record

USFS mast data

Raw ring-widths from 47 of the 664 individual trees (7.1%) correlated significantly with their mast data ($p < 0.1$; Appendix B). Of the trees with significant relationships, 29 in the red oak group (87.9%) displayed a negative correlation while four displayed a positive correlation. Fourteen trees in the white oak group (87.5%) correlated positively with mast and two negatively. Trees that correlated significantly had an average of 73% of remaining variance (after climate removal) explained by mast, and these trees tended to occur on sites that also exhibited significant stand-level relationships to mast.

Of the 55 site-species chronologies, 14 (25%) correlated significantly with mast ($p < 0.1$; Appendix C; Appendix D)—six of the 27 chronologies in the red oak group (22%) and eight of the 28 chronologies in the white oak group (29%). Five of the six red-oak-group correlations were negative, while four of the eight significant white-oak-group correlations were negative. A negative correlation implies a net cost to the tree, whereas a positive correlation suggests that, at the very least, the masting process does not tax the trees. We can consider only negative correlations with mast as successfully recording mast in the tree-ring chronologies. At least one site chronology of each species correlated significantly with mast. Scarlet oak and chestnut oak both produced three chronologies that correlated negatively with mast, which ranks them as the best mast recorders in this study. From 6.8% to 23.5% (mean=13.8%) of chronology variance was explained by mast alone.

Significant correlations of site-species chronologies with mast occurred at seven of the 17 sites. Tellico, Jackson Farm, Hurricane Gap, and Burnett Gap each produced more than one such chronology (Table 4-2). Tellico was the only site in which four species chronologies (black oak, chestnut oak, scarlet oak, and white oak) correlated significantly. The Tellico site also has one of the highest series intercorrelations of all the sites and was one of the most sensitive to climate (Table 3-2).

Analysis of the landscape characteristics (elevation, percent slope, aspect, terrain shape index, and landform index) of sites with significant correlations with mast versus sites that did not correlate with mast showed that aspect differed between the two populations (Figure 4-1 and 4-2). The sites that correlated with mast tended to be located on northwest-facing slopes (Figure 4-1), whereas sites that did not correlate with mast tended to be located on northeast-facing slopes (Figure 4-2). The percent slope also differed significantly between sites highly correlated with mast and those that were not ($t= -1.469$, $p < 0.1$). Sites that correlated significantly had a gentler slope (average slope = 17.6%) than sites that did not correlate with mast (average slope = 22.1%). Tellico, mentioned above, is located below the average elevation (587m) on a mid slope of 16.5% slope angle and with a northwest exposure.

Table 4-2. The number of chronologies on each site that correlated significantly to USFS mast data.

Site	*Number of significant chronologies*	*Number of chronologies*	*Percent correlated*	*Average r^2*
Hiawassee B	1	1	100%	0.310
Tellico	4	5	80%	0.130
Hurricane Gap	2	3	67%	0.140
Jackson Farm	3	5	60%	0.180
Old Gate	1	2	50%	0.110
Burnett Gap	2	5	40%	0.170
Buell Plot	1	4	25%	0.240
Hiawassee C	0	3	0%	0.000
Miller Ridge	0	3	0%	0.000
Cohuta	0	3	0%	0.000
Bike Trail	0	4	0%	0.000
Green's Lick	0	4	0%	0.000
Work Center	0	1	0%	0.000
Rice Pinnacle	0	2	0%	0.000
Tallulah	0	3	0%	0.000
Hard Times	0	3	0%	0.000
South Ridge	0	4	0%	0.000

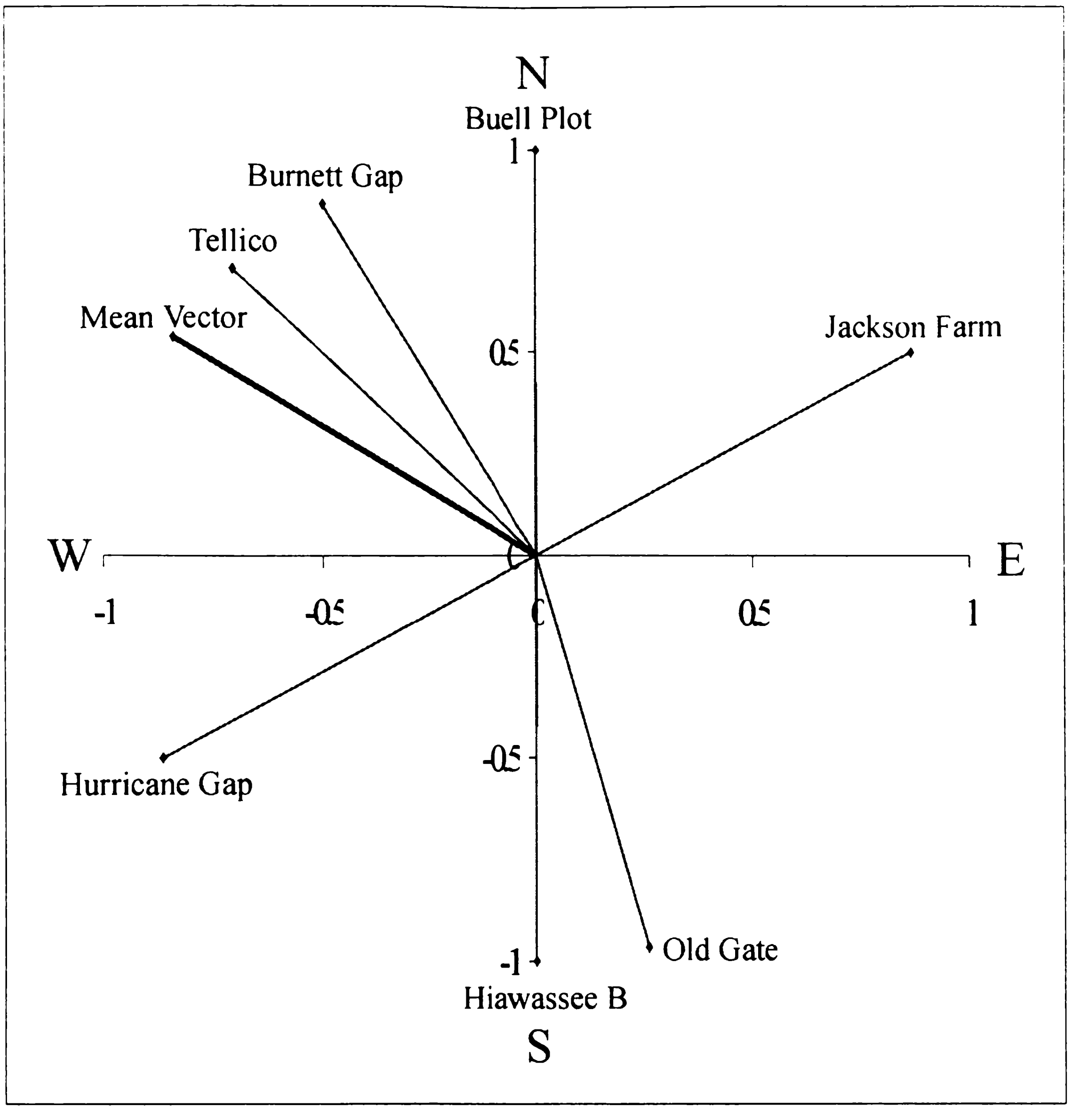

Figure 4-1. Rose diagram showing the aspect of the sites that were sensitive to mast. The sensitive sites tended to be on northwest facing slopes.

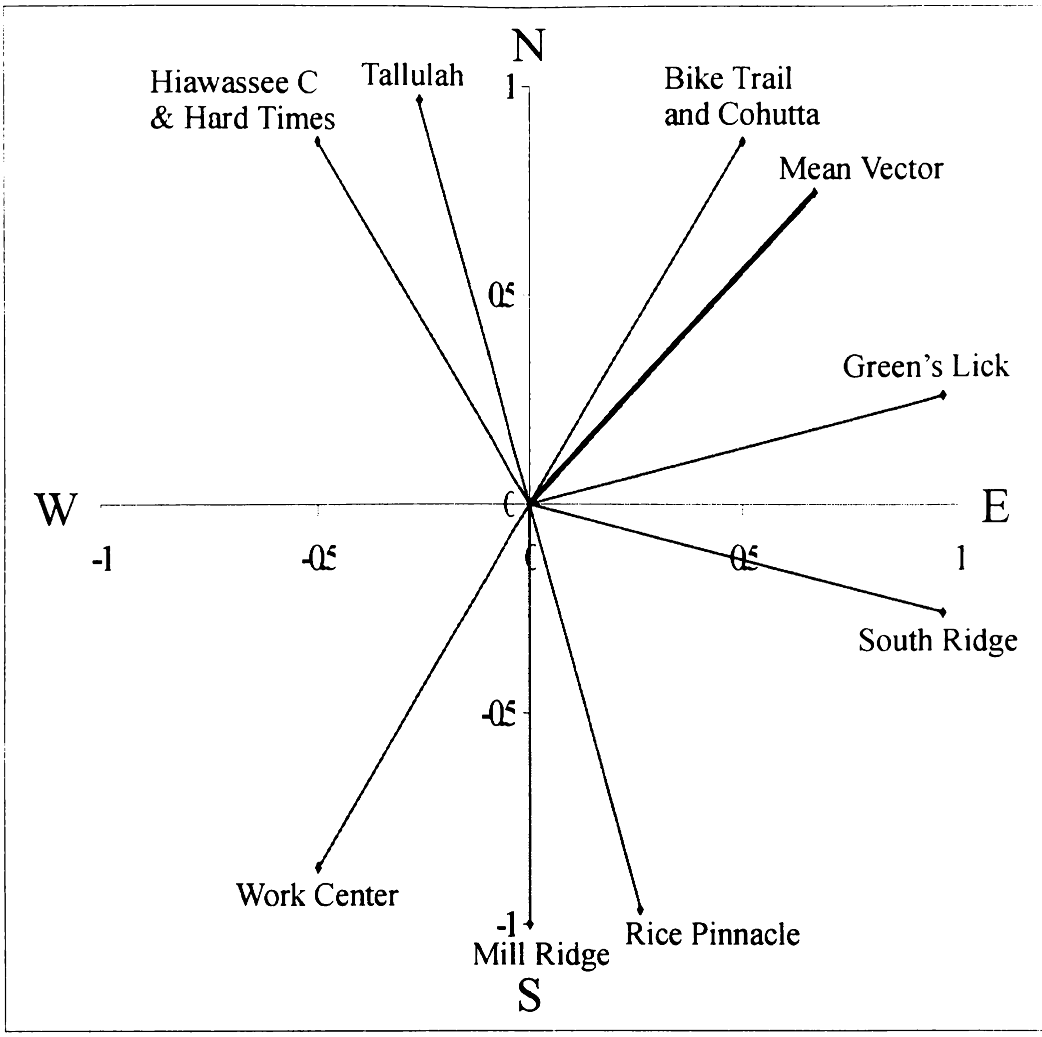

Figure 4-2. Rose diagram showing the aspect of the sites that were not sensitive to mast. The non-sensitive sites tended to be on northeast facing slopes.

SWRA mast data

While all five regional species chronologies correlated significantly with climate only one correlated significantly with mast (Figure 4-3). Climate explained 35.8% of the variance in the regional white oak chronology. Mast explained 19.0% of the remaining variance, so that 48.0% of the original variance in the regional white oak chronology was explained (Figure 4-4). We were able to reconstruct 103 years (1896-1999) of mast record with the regional white oak chronology (Figure 4-5).

Six of our 55 southern Appalachian site-species chronologies (10.9%) correlated significantly with local mast data from state Wildlife Resources Agencies ($p < 0.1$; Table 4-3; Figure 4-6 through 4-11). Climate and mast explained from 27.3% to 62.8% of the variance in these chronologies. Among these six chronologies, the climate models using PDSI and temperature explained an average of 22.5% (range = 4.4% to 34.4%) of the variance, and an average of 32.9% (range = 19.9% to 46.6%) of the remaining variance was explained by mast. Five of these six chronologies displayed negative correlations with mast, *i.e.* mast appeared as a net cost to the trees.

In the lag analysis, we would expect to find that year t-1 and/or t-2 were negatively correlated with the current year's mast if the trees were storing carbon reserves at the expense of radial growth. Only the Burnett Gap scarlet oak and Jackson farm white oak chronology showed this pattern, with year t-1 being negatively correlated with the current year mast data. The Jackson Farm white oak chronology, however, showed a positive correlation at year t-2, and no other chronologies had any significant correlations with years immediately preceding year t (Appendix E).

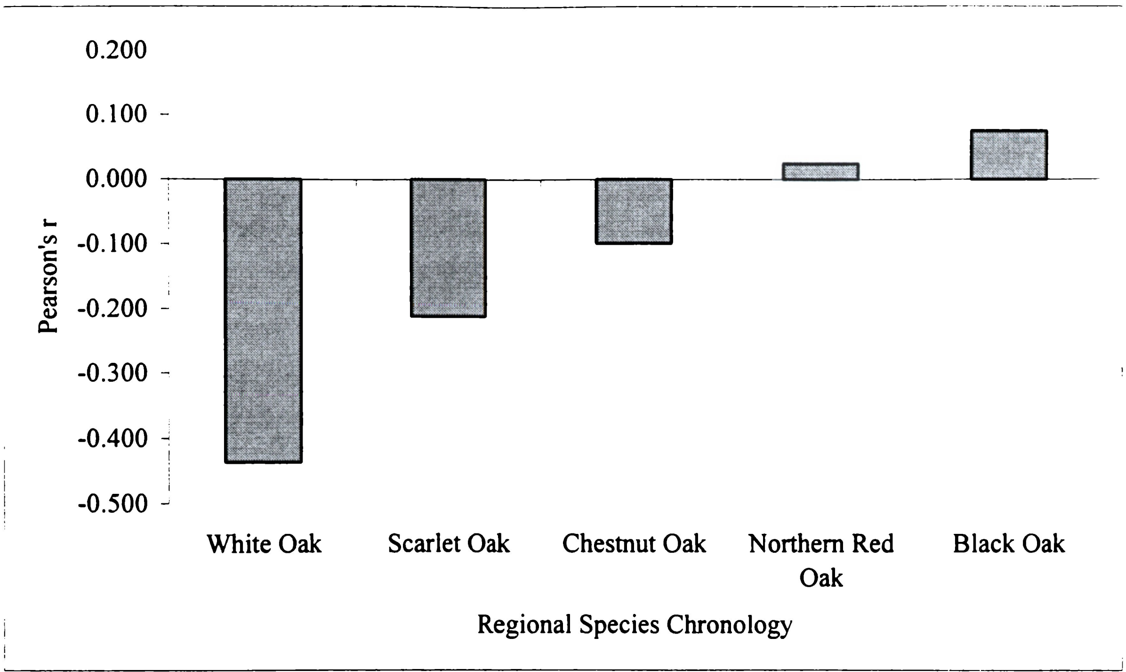

Figure 4-3. The correlation of the regional species chronologies to the regional mast data.

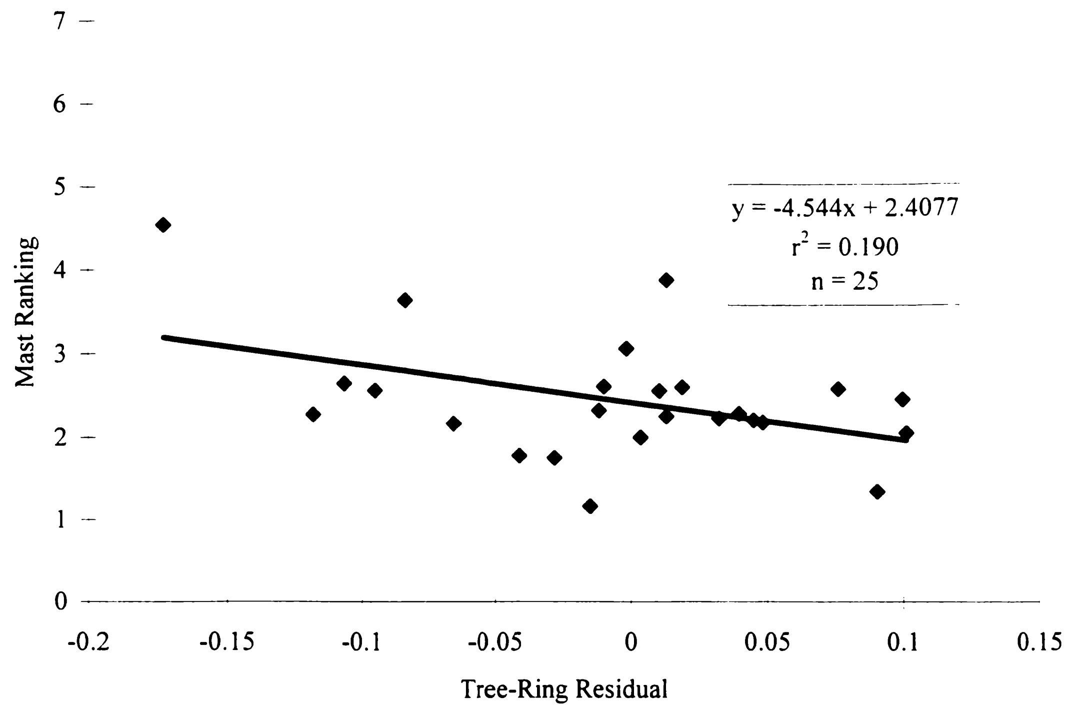

Figure 4-4. The regional white oak chronology versus the southeastern United States white oak group mast ranking.

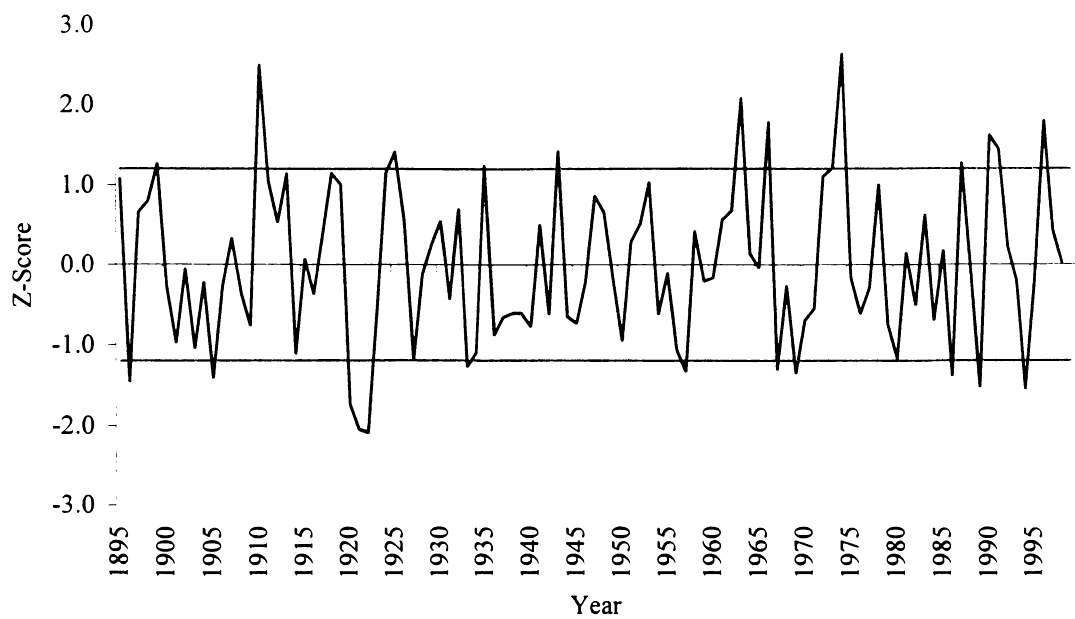

Figure 4-5. Regional white oak mast reconstruction. This reconstruction shows the past variability of mast years with z-scores of +1.2 or −1.2 considered extremely good or poor, respectively.

Table 4-3. County-level mast analysis. Six site-species chronologies in the southern Appalachians had a significant relationship (in bold) with county-level mast data, resulting in a regression equation that can be used to reconstruct mast. The variance explained by mast was calculated from the remaining variance in the chronology after climate has been removed. The *Total* r^2 is the amount of original chronology variance explained by both climate and mast. In the *Regression Equation*, y is the reconstructed mast ranking and x is the tree-ring residual.

Site	*Species*	*r*	R^2 *climate*	r^2 *mast*	*Total* r^2	*p of mast*	*Regression Equation*
Rice Pinnacle	**Scarlet oak**	**-0.683**	**0.155**	**0.466**	**0.549**	**0.005**	**y = -5.0801x + 2.857**
Tellico	**White oak**	**-0.659**	**0.344**	**0.434**	**0.628**	**0.001**	**y = -11.269x + 2.6674**
Tellico	**Chestnut oak**	**-0.577**	**0.316**	**0.333**	**0.544**	**0.006**	**y = -10.501x + 2.7222**
Cohutta	**Chestnut oak**	**0.551**	**0.294**	**0.303**	**0.508**	**0.041**	**y = 11.413x + 3.0665**
Jackson Farm	**White oak**	**-0.490**	**0.044**	**0.240**	**0.273**	**0.046**	**y = -10.278x + 2.4687**
Burnett Gap	**Scarlet oak**	**-0.446**	**0.196**	**0.199**	**0.356**	**0.095**	**y = -10.116x + 3.5194**
Bike Trail	Northern red oak	-0.425	0.117	0.181	0.277	0.114	
Burnett Gap	Northern red oak	-0.403	0.029	0.162	0.186	0.137	
Buell Plot	White oak	0.387	0.173	0.150	0.297	0.138	
Rice Pinnacle	White oak	0.373	0.070	0.139	0.200	0.170	
Buell Plot	Scarlet oak	-0.355	0.052	0.126	0.172	0.177	
Tellico	Northern red oak	-0.333	0.249	0.111	0.332	0.140	
Burnett Gap	White oak	-0.328	0.057	0.107	0.158	0.233	
Hiawassee B	White oak	-0.303	0.173	0.092	0.249	0.222	
Green's Lick	Northern red oak	-0.297	0.115	0.088	0.193	0.264	
South Ridge	Scarlet oak	-0.294	0.125	0.087	0.201	0.287	
Hiawassee C	Scarlet oak	-0.270	0.126	0.073	0.190	0.279	
Green's Lick	Chestnut oak	-0.265	0.202	0.070	0.258	0.360	
Hiawassee C	Chestnut oak	-0.259	0.258	0.067	0.308	0.316	
Hard Times	Scarlet oak	-0.251	0.133	0.063	0.188	0.348	
Buell Plot	Chestnut oak	-0.249	0.073	0.062	0.130	0.371	
Mill Ridge	Scarlet oak	-0.235	0.145	0.055	0.192	0.382	
Hurricane Gap	White oak	0.232	0.058	0.054	0.109	0.387	
Tellico	Black oak	-0.230	0.392	0.053	0.424	0.315	
Hurricane Gap	Northern red oak	0.228	0.030	0.052	0.080	0.396	
Cohutta	White oak	0.227	0.350	0.052	0.384	0.435	
Bike Trail	Black oak	0.206	0.158	0.042	0.194	0.480	
Old Gate	Scarlet oak	-0.194	0.127	0.038	0.160	0.487	
Jackson Farm	Black oak	-0.184	0.010	0.034	0.044	0.436	
Burnett Gap	Chestnut oak	-0.176	0.143	0.031	0.170	0.530	
Work Center	White oak	0.170	0.234	0.029	0.256	0.501	
Old Gate	Chestnut oak	0.162	0.235	0.026	0.255	0.563	
Jackson Farm	Scarlet oak	-0.159	0.003	0.025	0.028	0.502	
Jackson Farm	Northern red oak	-0.155	0.081	0.024	0.103	0.514	

Table 4-3 (Continued). County level mast analysis.

Site	*Species*	*r*	*R^2 climate*	*r^2 mast*	*Total r^2*	*p of mast*	*Regression Equation*
Green's Lick	White oak	0.141	0.132	0.020	0.149	0.601	
Green's Lick	Black oak	0.141	0.178	0.020	0.194	0.632	
Tallulah	Chestnut oak	-0.124	0.049	0.015	0.064	0.573	
Burnett Gap	Black oak	-0.122	0.192	0.015	0.204	0.664	
Jackson Farm	Chestnut oak	-0.122	0.104	0.015	0.117	0.654	
South Ridge	Chestnut oak	0.118	0.205	0.014	0.216	0.675	
Hard Times	Chestnut oak	0.116	0.347	0.013	0.356	0.682	
Tellico	Scarlet oak	-0.100	0.318	0.010	0.325	0.667	
South Ridge	Northern red oak	0.089	0.097	0.008	0.104	0.753	
South Ridge	White oak	-0.088	0.155	0.008	0.162	0.755	
Bike Trail	White oak	0.088	0.247	0.008	0.253	0.756	
Tallulah	White oak	0.088	0.114	0.008	0.121	0.691	
Tallulah	Northern red oak	0.086	0.124	0.007	0.130	0.698	
Buell Plot	Northern red oak	0.083	0.068	0.007	0.074	0.760	
Cohutta	Scarlet oak	0.076	0.213	0.006	0.218	0.796	
Bike Trail	Scarlet oak	0.071	0.032	0.005	0.037	0.800	
Mill Ridge	Chestnut oak	0.056	0.067	0.003	0.070	0.838	
Mill Ridge	White oak	-0.019	0.119	0.000	0.119	0.945	
Hiawassee C	Black oak	0.013	0.270	0.000	0.270	0.959	
Hard Times	White oak	0.004	0.285	0.000	0.285	0.990	
Hurricane Gap	Chestnut oak	-0.002	0.083	0.000	0.083	0.994	

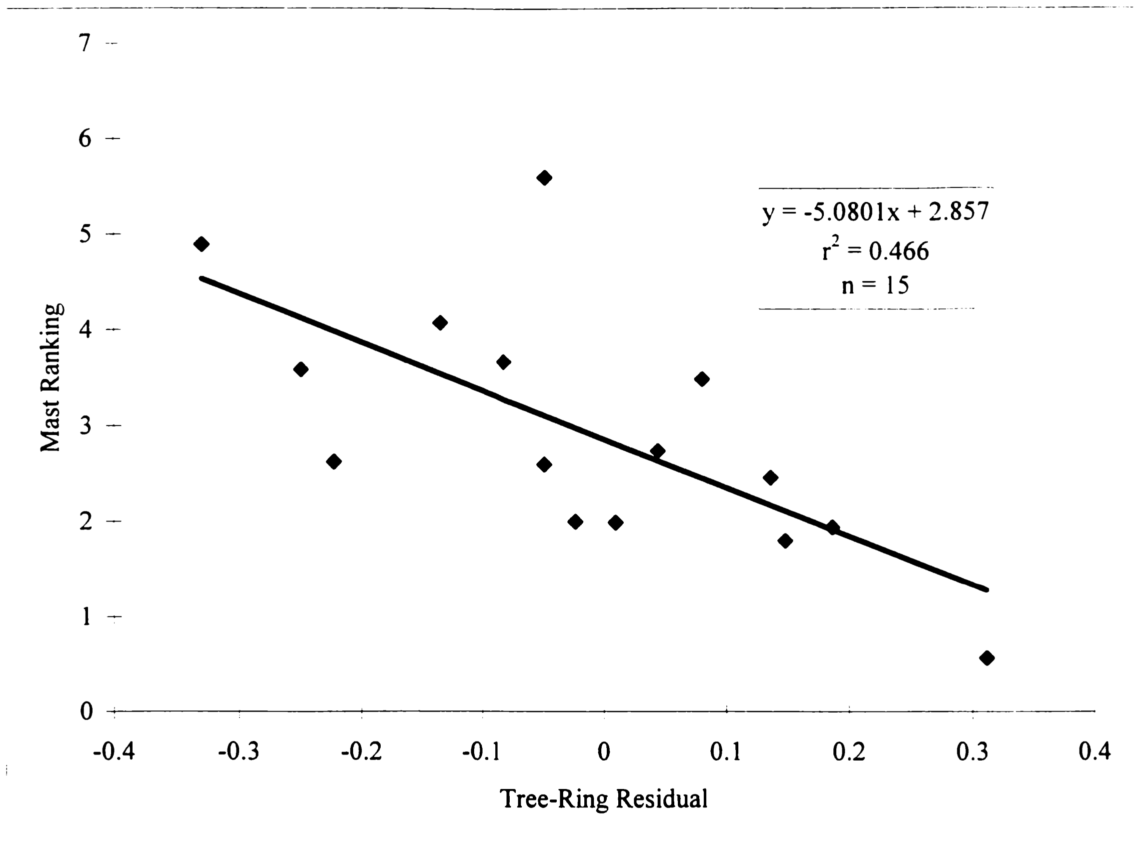

Figure 4-6. Rice Pinnacle scarlet oak tree-ring residuals versus western North Carolina red oak group mast ranking.

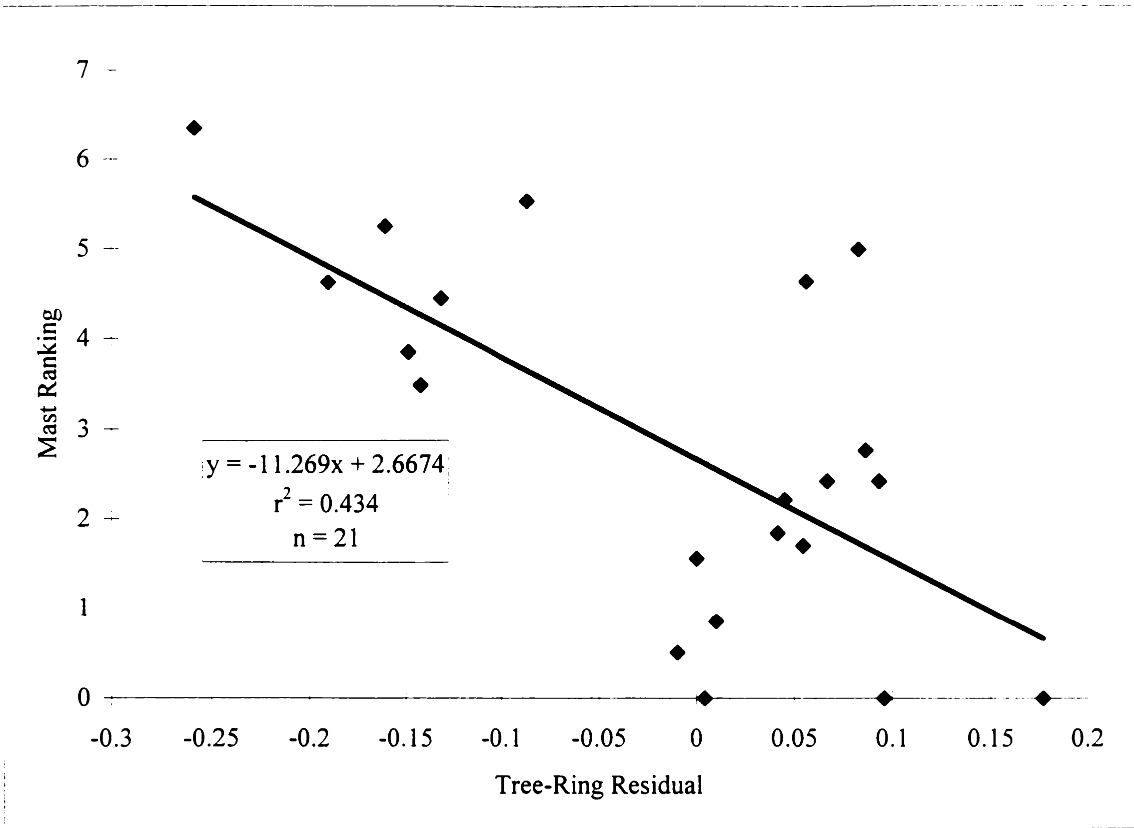

Figure 4-7. Tellico white oak tree-ring residuals versus Tellico Wildlife Management Area white oak group mast ranking.

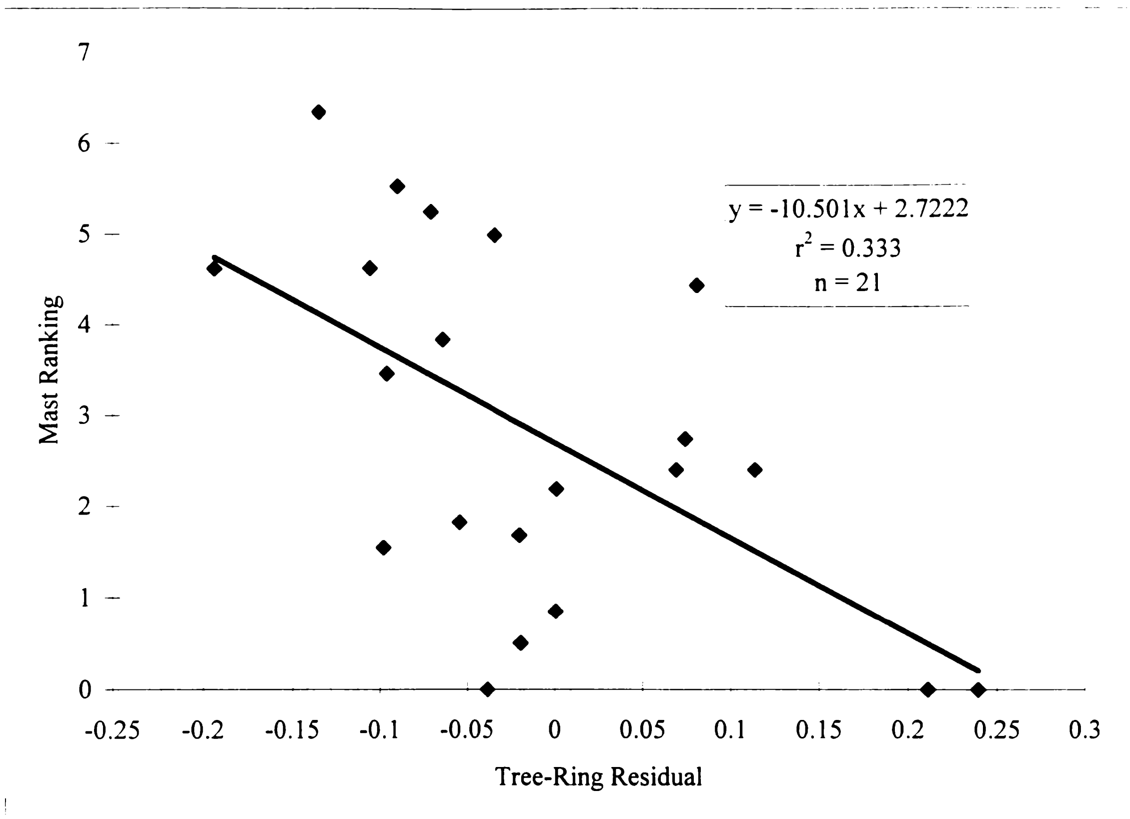

Figure 4-8. Tellico chestnut oak tree-ring residuals versus Tellico Wildlife Management Area white oak group mast ranking.

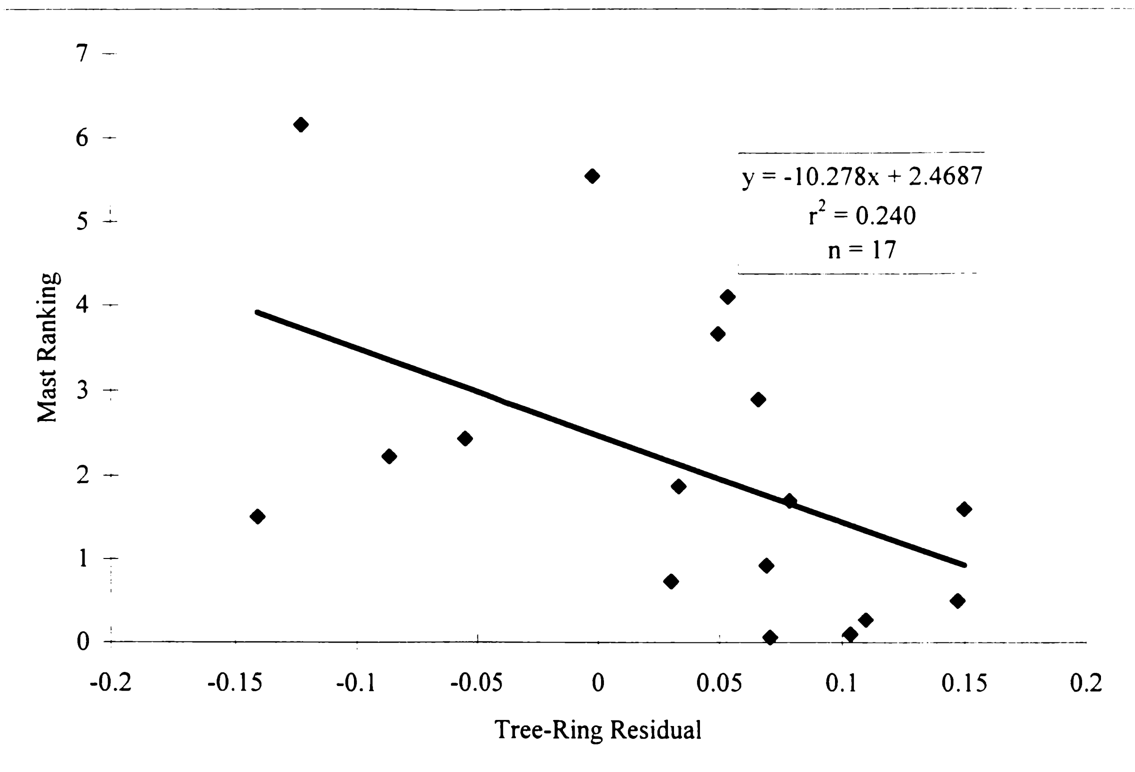

Figure 4-9. Jackson Farm white oak tree-ring residuals versus Greene County white oak group mast ranking.

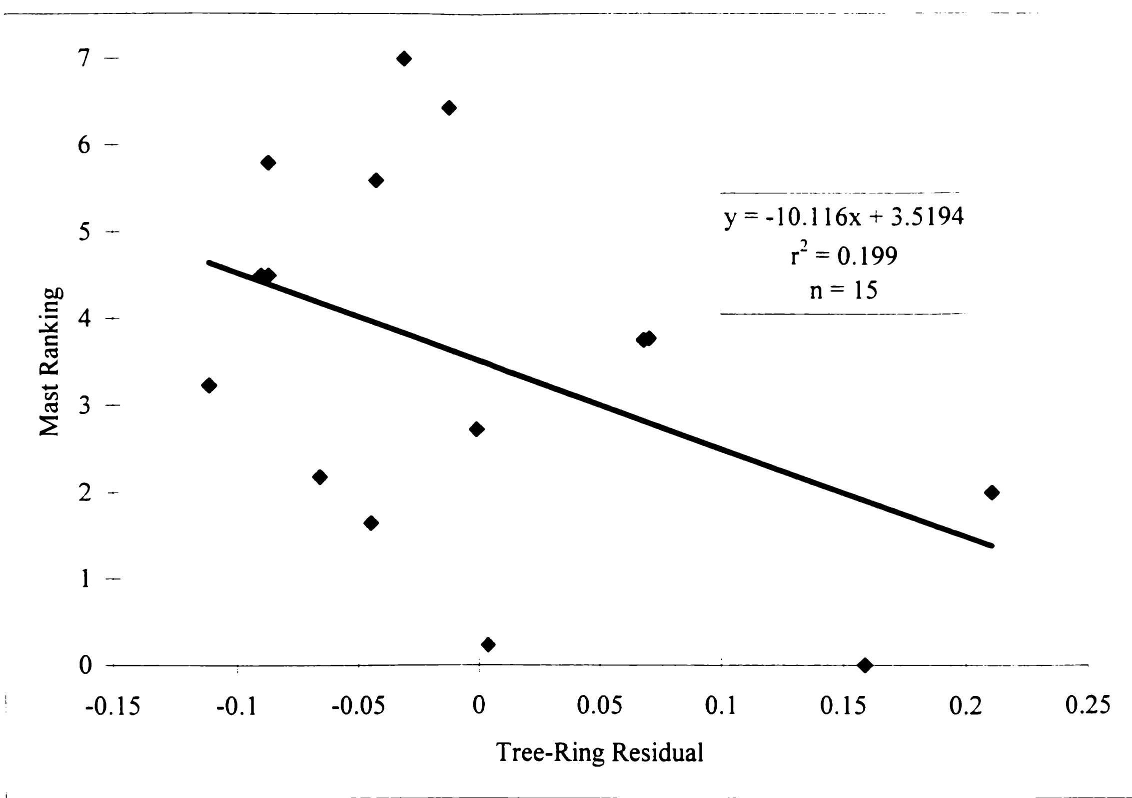

Figure 4-10. Burnett Gap scarlet oak tree-ring residuals versus Cocke County red oak group mast ranking.

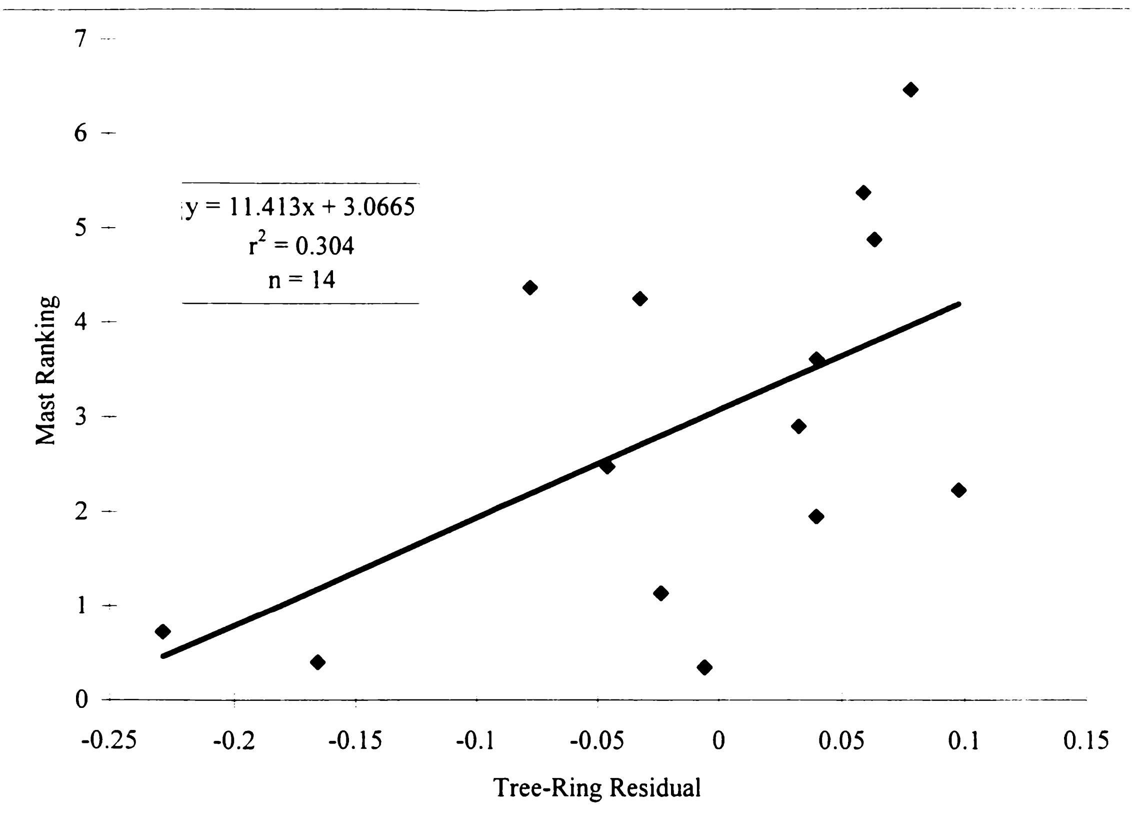

Figure 4-11. Cohutta chestnut oak tree-ring residuals versus Cohutta white oak group mast ranking.

We used the regression equations developed from the comparison with the SWRA county or regional data to calculate putative reconstructions of mast for the past 39 to 103 years depending upon the chronology (Figures 4-12 through 4-17). Some years are consistently reconstructed as good or bad mast years. At least 80% of the site-species mast reconstructions reported 1997, 1988, 1964, 1944, and 1936 as good mast years Table 4-4). All of these years also are recorded as good mast years in the regional white oak reconstruction. Both the regional white oak chronology and two of the site-species chronologies reported 1970, 1968, and 1928 as poor mast years (Table 4-5).

DISCUSSION

USFS tree-level mast data

Only 7% of individual trees recorded mast at a level discernable above background noise, suggesting that other factors besides the stress of massive fruit production are very often more important to carbon allocation at the tree level. We only had six years of data to analyze at the individual tree level but this should be large enough with 645 trees to demonstrate whether the trees are recording mast events, if significant masting occurred during those years. Based on the 24-year-long SWRA data sets (averaged over the southern Appalachian region), the six mast years covered by the USFS data were highly variable. The white oak group experienced the poorest mast year in 24 years in 1993 and one of the highest mast years in 1996. The red oak group of trees showed the second

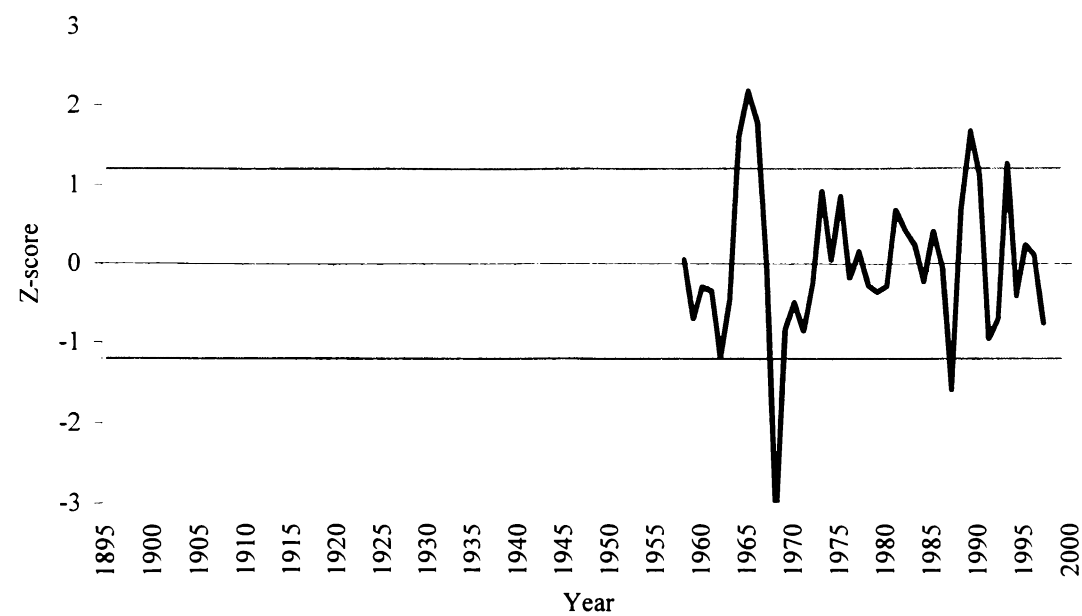

Figure 4-12. Rice Pinnacle scarlet oak mast reconstruction. This reconstruction shows the past variability of mast years with z-scores of +1.2 or –1.2 considered extremely good or poor, respectively.

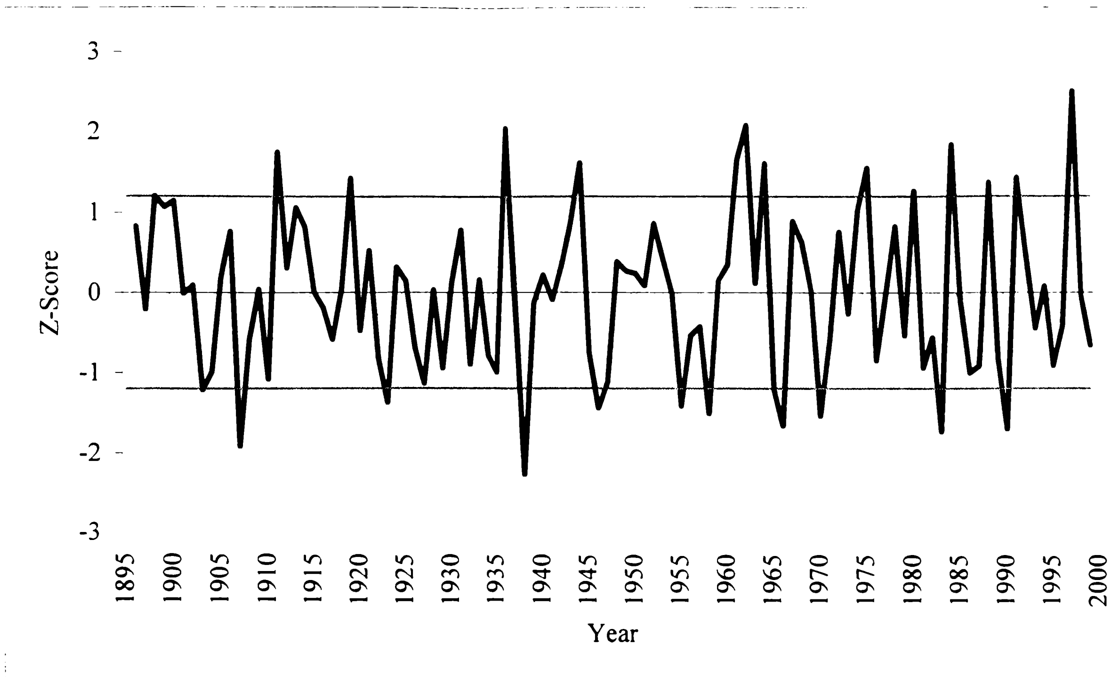

Figure 4-13. Tellico white oak mast reconstruction. This reconstruction shows the past variability of mast years with z-scores of +1.2 or –1.2 considered extremely good or poor, respectively.

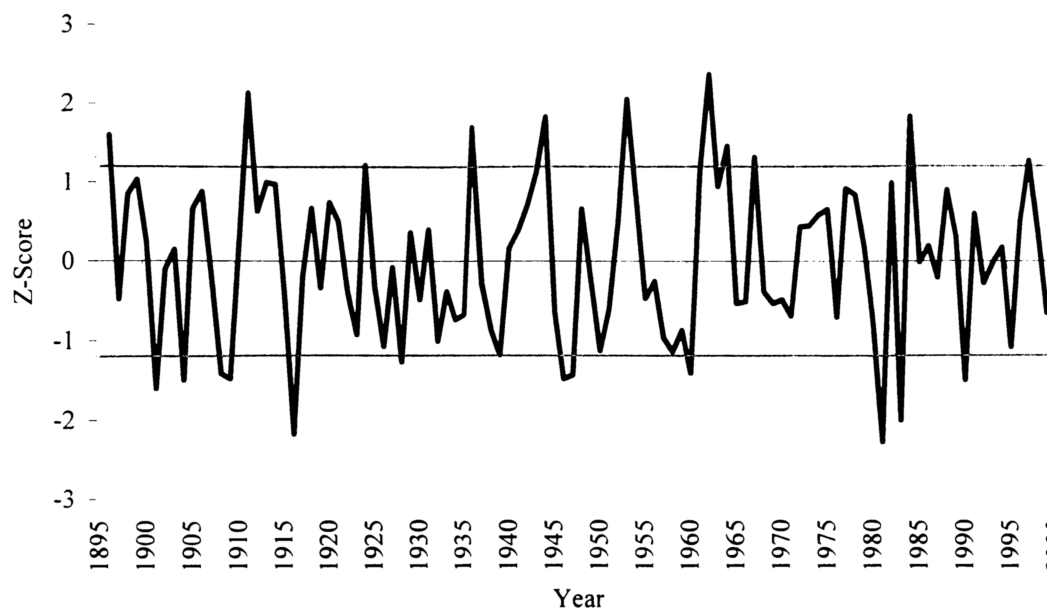

Figure 4-14. Tellico chestnut oak mast reconstruction. This reconstruction shows the past variability of mast years with z-scores of +1.2 or –1.2 considered extremely good or poor, respectively.

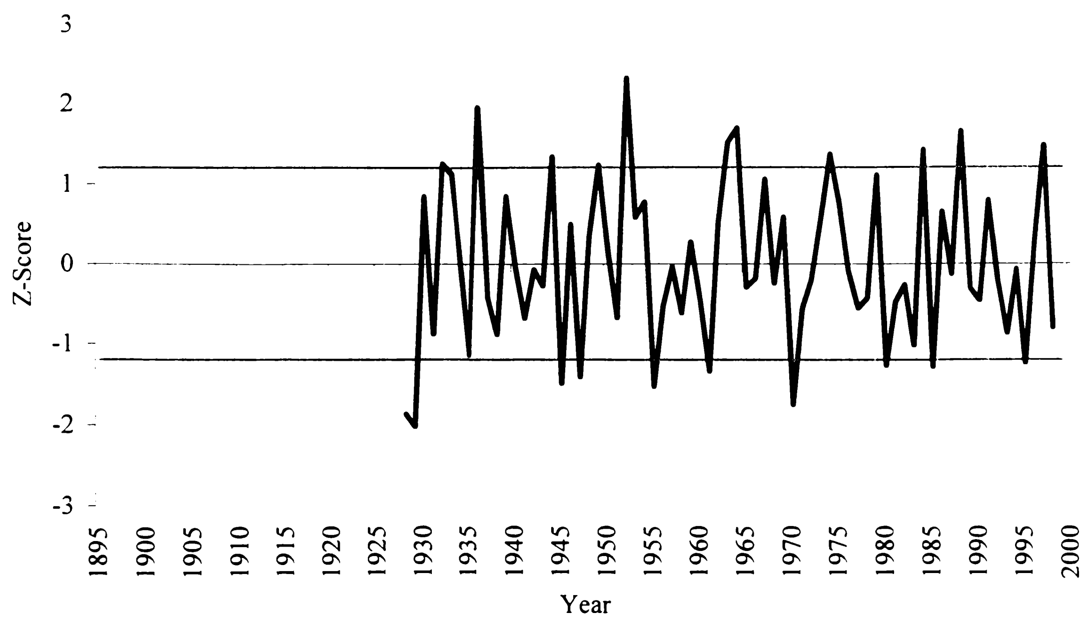

Figure 4-15. Jackson Farm white oak mast reconstruction. This reconstruction shows the past variability of mast years with z-scores of +1.2 or –1.2 considered extremely good or poor, respectively.

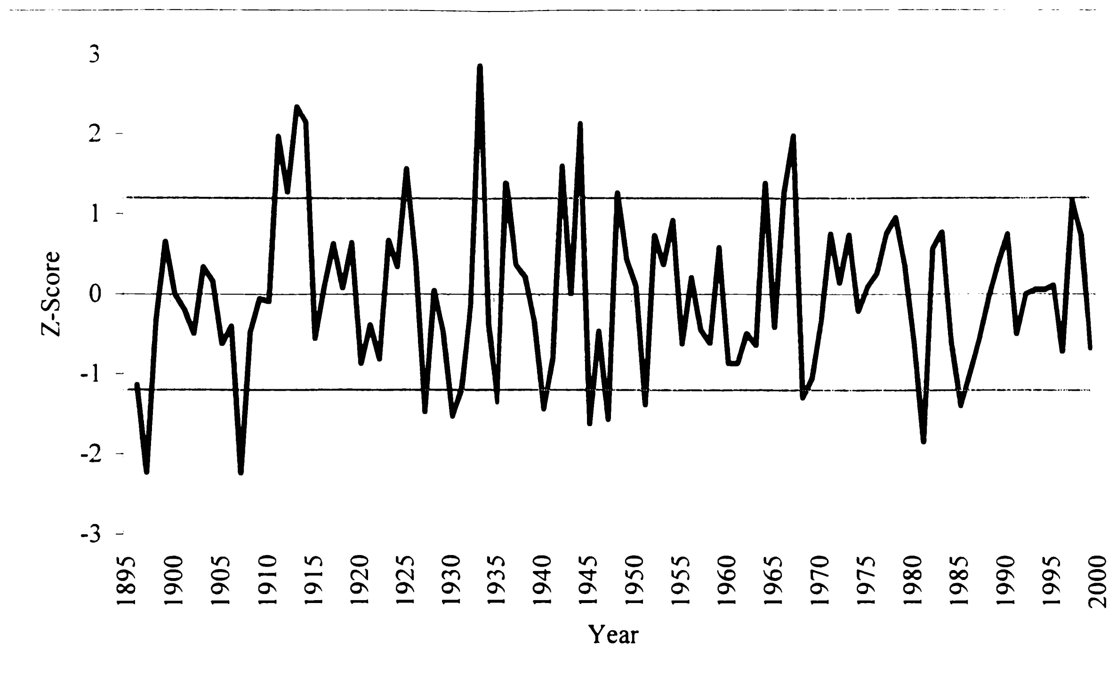

Figure 4-16. Burnett Gap scarlet oak mast reconstruction. This reconstruction shows the past variability of mast years with z-scores of +1.2 or –1.2 considered extremely good or poor, respectively.

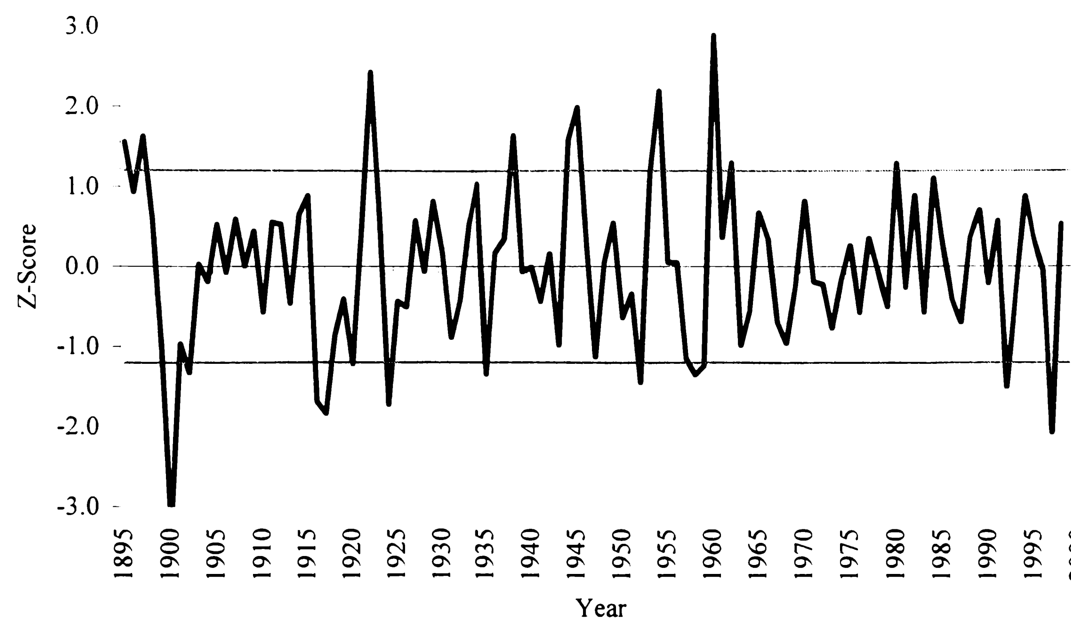

Figure 4-17. Cohutta chestnut oak mast reconstruction. This reconstruction shows the past variability of mast years with z-scores of +1.2 or –1.2 considered extremely good or poor, respectively.

Table 4-4. Reconstructed good mast years from the five chronologies with significant negative correlations.

Year	*Number of Sites Recording a Good Mast Year*	*Number of Sites Recording*	*Percent pf sites recording*
1997	4	5	80%
1988	4	5	80%
1984	3	5	60%
1967	2	5	40%
1964	5	5	100%
1962	2	5	40%
1961	2	5	40%
1944	4	4	100%
1936	4	4	100%
1911	3	4	75%

Table 4-5. Reconstructed poor mast years from the five chronologies with significant negative correlations.

Year	*Number of Sites Recording a Bad Mast Year*	*Number of Sites Recording*	*Percent pf sites recording*
1990	2	5	40%
1985	2	5	40%
1983	2	5	40%
1970	2	5	40%
1968	2	5	40%
1955	2	4	50%
1946	2	4	50%
1928	2	4	50%
1907	2	3	67%

worst mast year in 1997 and two of the best five mast years in 1995 and 1998. Individual tree growth is probably affected strongly by competition for light and nutrients. By averaging a relatively large number of trees on one site, we reduced such individual tree variability, and the resulting site-species chronology proved more likely to reveal broad-scale patterns (such as climate and masting) that affect all trees.

Stand level analysis produced stronger results overall. Using the USFS data, the number of observations is greatly increased (average of 31 tree-years and maximum of 82), enabling more robust analysis. We are still using the same six years of mast and ring-width data, but we are analyzing all trees of a given species in a stand at once. At this level, 25% of the site-species chronologies correlated significantly with mast. All five species correlated significantly with mast on at least one site, although scarlet oak and chestnut oak seemed to be the most sensitive species.

Aspect and percent slope were the only measured landscape characteristics that appeared to differ between mast-sensitive sites and non-sensitive sites. The sites that were sensitive to mast tended to be on northwest-facing slopes, while those that were not sensitive to mast tended to face northeast. Mast-sensitive sites were also generally on more gentle slopes than sites that did not record mast. Tellico was by far the most sensitive site, with four of its five species chronologies correlated significantly with mast. This site supported the general findings for mast sensitive sites, in that it is located on a northwest-facing, relatively gentle slope (18.1%). In dendroclimatology, northwestern gentle slopes are not usually considered ideal for northern-hemisphere climate reconstructions. Trees in these positions are not as stressed by a lack of soil moisture as those on a steep south-facing slope. The occurrence of mast-sensitive sites on gentle northwest-facing slopes might indicate that favorable growing conditions allow biological factors such as masting to gain importance in controlling tree growth.

SWRA county- and regional-level mast data

The SWRA data spans 16 to 24 years, allowing more robust analysis although at county and regional resolution. After climate was removed from the tree-ring chronologies, 10.9% of the site-species chronologies correlated significantly with mast records, and the amount of variance explained by mast increased. An average of 16.9% of the original variance was explained by mast without removing climate, while 32.9% of the remaining variance was explained by mast after removal of climate.

After climate subtraction, tree growth had a negative correlation with mast in both the red oak and white oak groups with the single exception of the Cohutta chestnut oak chronology. This result contrasted with the stand-level analyses (using the USFS tree-level mast data with no climate removal), in which we found significant results with both positive and negative correlations. This may suggest that some site-species chronologies truly reflect the cost of mast production (and therefore demonstrate a narrow ring during heavy mast years irrespective of climate), while others reflect a covariant response to climate. If both tree growth and mast respond in some degree to favorable weather conditions the year the acorns are on the tree, then both may increase in parallel. The few positive correlations with mast before climate was removed may reveal such a concurrent response. Results after removing climate showed that this covariance is partial and the masting signal is actually negative. In future mast reconstructions, we advise climate subtraction to enhance the mast signal and to remove climate as a confounding factor.

Implications for mast ecology

We hypothesized that masting should result in a strict tradeoff between incremental growth and reproductive effort in both the stand- and tree-level chronologies. We found that only 25% of the stand-level chronologies and 7% of the tree-level chronologies significantly correlated with the mast data. After controlling for climate, 10.9% of the site-species chronologies were shown to reliably record mast. Consequently, we conclude that mast is not a major growth-limiting factor in most southern Appalachian oak trees or stands, which brings the prediction of the evolved strategies hypothesis into question.

A complex of mechanisms involving both triggered masting and carbon storage seems to be indicated. Because we occasionally found oak sites in which tree growth was sensitive to masting, we believe that resource switching does occur. The alternative hypothesis of resource accumulation, in which the trees build up ample resources before a mast event is triggered, would result in a gradual lagged response to masting and would not reduce ring width in any of the trees the year of the mast event. However, the fact that sensitivity to mast is evident in some cases but not others would suggest that carbon storage occurs on a moderate level, but that carbon stores at some sites are insufficient to avoid a drain on current-year resources.

The finding may not hold true in other genera or locales although similar results were found in California oak trees. Knops and Koenig (unpublished manuscript) did not find a tradeoff between tree growth and reproduction in three oak species in California. They also reviewed other literature examining the tradeoff question and found that only five of 15 studies have found any significant evidence of a tradeoff between tree growth and reproduction. They state that although tradeoffs between growth and reproduction may occur in some temperate trees, these tradeoffs are neither universal nor very strong. Silvertown and Dodd (1999) suggested that a tradeoff between growth increment and seed production in balsam fir (*Abies balsamea* (L.) Mill.) did exist, although their data only showed that a minor amount of the variance in growth loss was explained by seed production, and this relationship was not significant. They found a stronger, significant relationship between height growth and seed production (7% of variance explained).

All of these findings suggest that, to some degree, trees must use stored reserves for mast production, so that the drain caused by masting in oaks does not fall only on the year the acorns are on the tree, but is instead a smooth pattern over several years building up to a mast event. We did not find any evidence of a dramatic drain of resources in the years leading up to a heavy mast event, suggesting that strongly cyclic resource accumulation is not the main mechanism functioning in southern Appalachian oaks. However, this does not rule out the possibility of continual, non-cyclic resource accumulation and triggered release. In that case, the pattern would likely be too complex and subtle to be easily seen in regression analysis.

CONCLUSIONS

These are the first mast reconstructions ever attempted using dendrochronology and should therefore be interpreted conservatively. These putative reconstructions need to be tested further to determine if they truly track the mast patterns in these oak trees. One possible test would be to compare our reconstructions with wildlife population data to determine whether historic population responses match our mast reconstructions. This next step is taken in chapter 5, in which we compare two of the mast reconstructions to black bear population estimates in GSMNP and to black bear harvest data from western North Carolina.

We have considerable confidence in the degree to which our reconstructions are accurate reflections of past conditions, based on the patterns that are present in the data. At least 80% of the site-species mast reconstructions and also the regional white oak reconstruction selected 1997, 1988, 1964, 1944, and 1936 as good mast years. We had better success at reconstructing heavy mast events than poor ones, which is expected. Because a heavy mast event is a drain on tree resources, we expected that the trees would be more sincere recorders of these events, whereas mast failure may be rooted in multiple causes.

Further mast reconstructions in new regions are certainly possible, but a mast record for the region will have to be present to help develop the regression equation. Because a known mast record must be used to calibrate regression equations on a stand and species basis, we recommend finding good quality mast records and then working to develop mast reconstructions locally. Future research, however, may be constrained by the scarcity of mast data. There does appear to be a relatively strong regional signal from mast, which may facilitate regional mast reconstructions. While mast data are not widespread, there are some data present worldwide. Koenig and Knops (2000) compiled a database of published mast records that includes 443 sets of data from 72 different literature sources. Ten genera in three different plant families were represented. The average length of the records was 11.7 years and the longest record lasted 55 years. Such records can be used as calibration data sets to start mast reconstructions around the world. In other cases, research like the USFS study used here will have to be initiated.

The methods developed here for mast reconstruction produce positive results. We were able to identify a reduction in ring width in many site-species chronologies and were able to develop mast reconstructions using this relationship. This new technique, which we call dendromastecology, shows strong potential for new findings using the tools of dendrochronology. We expect this technique will prove useful with other tree genera and will help develop long-term mast records that can be used by wildlife managers and tree ecologists to answer questions about the mechanisms driving wildlife population dynamics, mast fruiting, and tree regeneration pulses.

Chapter 5

The Application of a Dendrochronological Mast Reconstruction to Examine Black Bear Population Dynamics in the Southern Appalachians

INTRODUCTION

The purpose of this study is to determine whether associations exist between reconstructed mast availability and black bear populations in the southern Appalachians. Positive associations would demonstrate the applicability of mast reconstructions to wildlife management. To accomplish this, we compare two mast reconstructions with two black bear (*Ursa americanus*) population estimates: mark-and-recapture data from the Great Smoky Mountains National Park (GSMNP), and black bear harvest data from three counties in western North Carolina.

The habitat in the southern Appalachians consists largely of second-growth forests, primarily eastern deciduous forests in which oaks are the dominant arboreal species. Oak mast is important to wildlife because it provides a food source that is high in fats and carbohydrates (Table 5-1). Studies have shown that oaks are an important food source for black bears because of acorns' "nutritional content, digestibility, amount of energetic production, and timing of that production" (Pelton 1989). Inman (1997)

Table 5-1. Nutritional value of various black bear foods found in the northwest quadrant of the Great Smoky Mountains National Park (modified from Inman 1997).

Food species	*Mast Type*	*Sample Type*	*Mean dry weight of 1 fruit (grams)*	*Cal/g*	*Mean Cal /1 fruit*	*N*
Squawroot	S	Whole stalk	9.231	4.662	43.03	8
Chestnut oak	H	whole fruit	2.992	4.188	12.53	57
N. red oak	H	whole fruit	2.220	4.541	10.20	35
Scarlet oak	H	whole fruit	0.667	4.259	2.84	30
White oak	H	whole fruit	0.668	4.054	2.71	33
Thornless blackberry	S	whole fruit	0.166	5.271	0.87	160
American Beech	H	Outer husk removed	0.174	4.609	0.80	80
Hickories	H	meat only	0.151	4.534	0.68	50
Grapes	S	whole fruit	0.093	4.901	0.46	245
Greenbriers	S	whole fruit	0.095	4.444	0.42	178
Blackgum	S	seed removed	0.082	4.982	0.41	142

suggested that oaks may be the single most influential plant genus affecting bear ecology in the southern Appalachians. Acorns are the main food source during the period when bears store energy for hibernation. Acorn crops have significant effects on the annual natality and survival rates of bears in the southern Appalachians. Eiler *et al.* (1989) showed that low reproductive success (26.1%) and high cub mortality (87.5%) occurred in the years after poor mast crops in this region. The carrying capacity of an area for bears may be determined by the abundance of oaks (Inman 1997).

Mast reconstructions

We used two different mast reconstructions in this analysis. One was developed from white oak on the Tellico site, which is near the southwestern quadrant of the GSMNP where the black bear mark-and-recapture data were collected. The other chronology was constructed for the southern Appalachian region covering eastern Tennessee, western North Carolina, and northern Georgia. Our mast reconstructions span 103 years (1896-1999) and were limited by the length of the record used to remove climate from the tree-ring chronology (Chapter 3). In the Tellico white oak mast reconstruction, mast explained 43.4% of the remaining variance after the removal of climate variance, which explained 34.4% of the original variance. The total variance explained by mast and climate in this tree-ring index chronology was 62.8%. In the regional white oak chronology, mast data explained 19.0% of the remaining variance after climate removal, which explained 35.8% of the original variance. Together, these variables accounted for 48.0% of the original variance in the regional white oak index chronology.

Bear population estimates

We hypothesize that previous years of good mast production should have a positive influence on the current year's bear population. Because the availability of acorns affects cub litter size and survival, a good mast year should result in an increase in bear populations the year after the mast is produced. This effect also will propagate through time because higher populations will mean a greater reproductive potential in subsequent years. The inverse is true for poor mast years. Five years would probably be the longest temporal window in which we would observe a primary correlation between mast and the bear population. The progeny of this generation may still show the effect of a good or bad mast year over broader temporal scales, but that should be a secondary, much weaker signal. We considered these interactions in choosing a window of 0-5 years of lagged mast records to explore the relationship between mast and bear population.

Black bear mark-and-recapture data 1972-1999

The mark-and-recapture data were collected in the northwest quadrant of the GSMNP. A team of researchers from the University of Tennessee Department of Forestry, Wildlife, and Fisheries captured black bears during summer and marked them with ear tags and lip tattoos. The capture histories of these bears were used to estimate the adult black bear population since 1972 using the Jolly-Seber population estimation (F. van Manen, pers. comm.). The mark-and-recapture protocol only records bears (as part of the adult population) once they have reached 1.5 years of age and leave the protection of their mothers.

North Carolina bear harvest data 1976 - 1998

Harvest records constitute reported kills by hunters during the black bear hunting season. We used bear harvest data collected by the North Carolina Wildlife Resources Agency (from 1972 to 1999) in Buncombe, Haywood, and Madison Counties. We chose these three counties because they were centrally located with respect to our tree-ring sample sites.

Using any harvest data as an indicator of population numbers is admittedly biased by a number of factors. Harvest records only count the number of legally hunted animals; poaching is not considered. Poaching does occur in the southern Appalachians, but is considered minor compared to the number of bears harvested legally. Besides the availability of food for the bears, the success of the hunting season depends upon a number of factors including the weather during the hunting season (which affects the number of hunters that choose to hunt and the conditions of visibility during the hunt) and changes in hunting technology through time. Even considering these factors, we make the assumption that the bear harvest record is a satisfactory estimate of the bear population through time. We base this assumption on the underlying principle that more bears on the landscape will increase the probability of bear-hunter encounters.

A number of mechanisms can cause a higher number of bears to be taken in any given year. If more bears are taken because populations are high, we would expect a positive association between bear populations and mast two or more years prior. A bear can be legally hunted when it reaches 100 pounds. Usually, this occurs at the end of its second year or the start of its third year. In this case, previous good mast years may be more important than the current mast year. We also hypothesize that a positive relationship may occur between harvest data and mast in the current year because a good mast crop will keep the bears active on the landscape farther into the winter than during years of a poor mast crop (J. Pack pers. comm., West Virginia Department of Natural Resources). The gun hunting season for bears in much of the southern Appalachians is during the month of December, so that the current year mast crop, and its effect on the timing of denning, can greatly affect the success of the bear hunting season..

METHODS

Mast reconstruction

To develop the mast reconstructions, we first located sites in the southern Appalachians that the U.S. Forest Service was using to study the amount of mast produced by oak trees. We cored trees on these sites using an increment borer, taking two cores per tree on opposite sides of the trees. We dated each core using standard dendrochronological procedures (Stokes and Smiley 1968), and then measured the tree-rings using a Velmex measuring system. The program ARSTAN was used to develop stand- and regional-level tree-ring chronologies (Chapter 4).

The Tellico site is located on a northwest facing slope at 587 m elevation. This site is located approximately 50 km southwest of the GSMNP where the bear mark-and-recapture data were collected. We used 36 cores from 18 white oak trees to develop the stand-level tree-ring chronology from this site. We chose the Tellico site for this analysis because, of the 17 sites in our study, it was closest to the area where the mark-and-recapture data were collected.

For the regional white oak chronology we used 339 cores from 169 white oak trees on 17 sites in eastern Tennessee, western North Carolina, and Northern Georgia. The sites represent a wide variety of elevations and topographic conditions. By averaging the index chronologies from multiple sites, we were able to isolate regional signals of mast and climate.

Climate is usually the strongest signal recorded in the annual growth of trees but nonetheless constitutes "noise" in our study. We removed climate by conducting a regression analysis between Palmer Drought Severity Index (PDSI), temperature, and our tree-ring chronologies (Chapter 3). The residual values from that regression contained the non-climatic variance of the chronologies. For the Tellico site, we regressed the residual chronology with the Tellico Wildlife Management Area mast data that extended back 24 years. We regressed the regional white oak residual chronology with aggregate mast data from Tennessee, North Carolina, and Georgia collected by the state Wildlife

Resource Agencies. Both of these regressions provided models that reconstructed mast for the past 103 years (1896-1999; Chapter 4).

Comparison to wildlife data

The mark-and-recapture data from GSMNP and the bear harvest data from western North Carolina both exhibit a positive exponential trend in the number of bears through time. We believe that this trend is an accurate representation of bear population, which seems to have been increasing since the development of protected areas such as the GSMNP. The trend would be certain to confound regression analysis of masting and population response, and needed to be removed from the data. We fit a positive exponential curve and standardized the data (*sensu* Estes 1970) using Equation V.

$$Z_t = (N_t - Y_t) / Y_t \qquad [V]$$

where Z_t is the index value at time t, N_t is the population estimate, and Y_t is the value of the standardization curve. The resulting population indices displayed no overall trend through time (Figures 5-1, 5-2, 5-3, and 5-4), while keeping short-term change information.

We used correlation matrices to explore the relationship between our mast reconstructions (year t, t-1, t-2, t-3, t-4, t-5) and the two bear population indices. This revealed the years, current and lagged, that significantly correlated with the bear population indices. If more than one year was indicated, we used multiple linear regression in SPSS (Norusis 1999) to determine a best-fit model for population-index

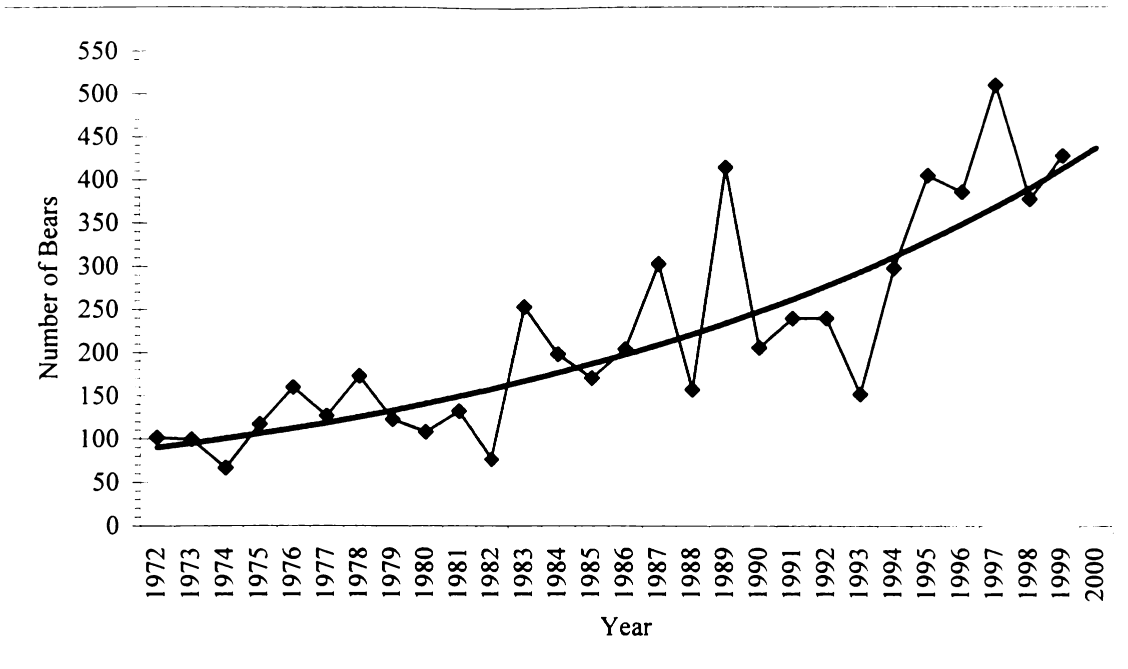

Figure 5-1. Standardization curve for the mark-and-recapture bear population estimates.

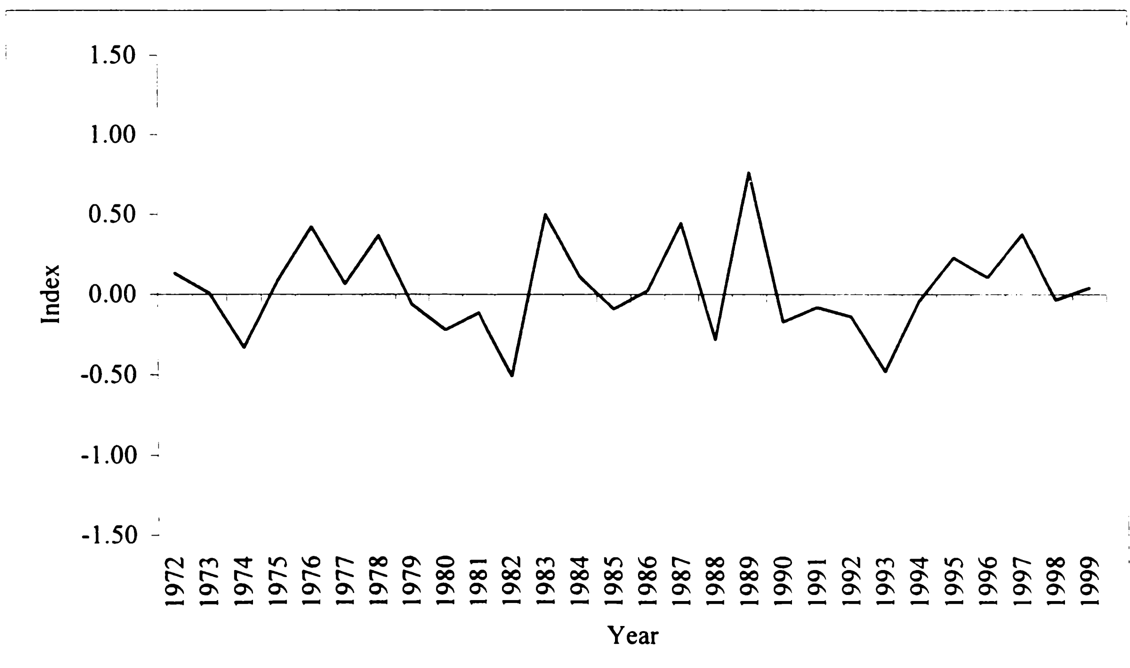

Figure 5-2. Index series for the mark-and-recapture bear population estimates after being standardized with a positive exponential curve.

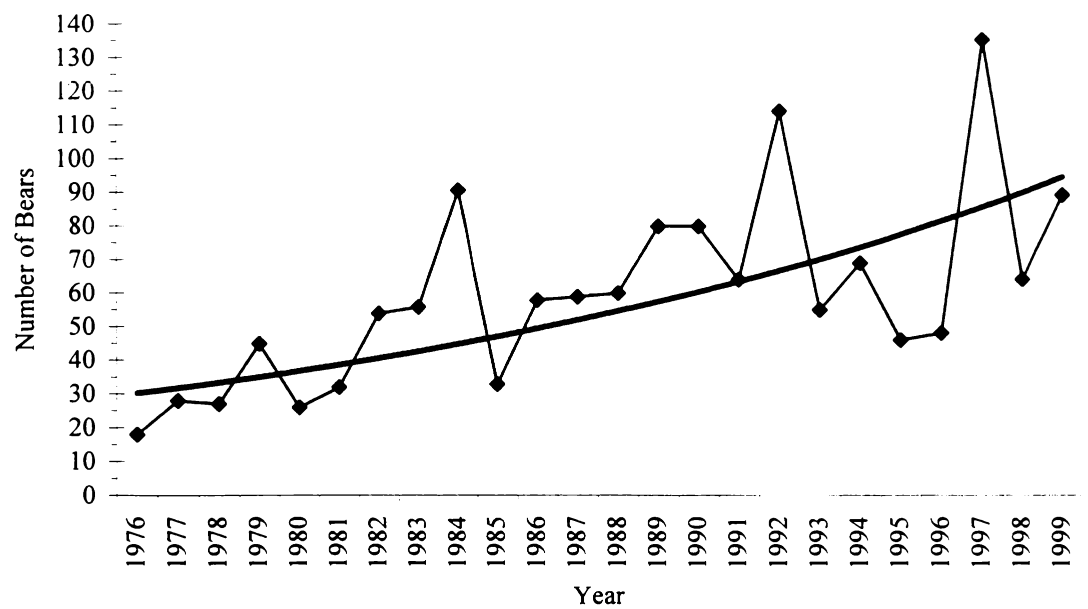

Figure 5-3. Standardization curve for the western North Carolina bear harvest data.

Figure 5-4. Index series of the western North Carolina bear harvest data after being standardized with a positive exponential curve.

response to mast. This analysis provided an estimate of the amount of variance in the population indices that was explained by our mast reconstructions.

One of the assumptions of regression analyses is that the time series must not be autocorrelated. We used the Durbin-Watson statistic (D-W) to determine the degree and sign of series autocorrelation (Ostrom 1978). A D-W value of 2 means that the series are not autocorrelated and a score between 1.6 and 2.4 is acceptable. A time series with a D-W less than 1.2 or greater than 2.8 is highly autocorrelated and must be rejected.

RESULTS

The correlation analysis showed that only mast in year t-3 correlated significantly with the mark-and-recapture bear population index ($r = 0.340$; $p < 0.1$). This was a positive correlation suggesting that a heavy mast crop three years prior may have resulted in a higher adult bear population in the current year. The harvest data index had a significant positive correlation with mast in year t and a negative correlation in year t-2 ($r = 0.446$ and $r = -0.420$ respectively; $p < 0.05$) (Figure 5-5 and 5-6).

We developed a simple linear model for the association between the mark-and-recapture index and the Tellico white oak mast reconstruction at year t-3, explaining 11.5% of the variance (Equation VI; Figure 5-7) (D-W = 2.213; $p < 0.1$).

$$y_t = 0.0849 * x_t - 0.1767 \qquad \text{[VI]}$$

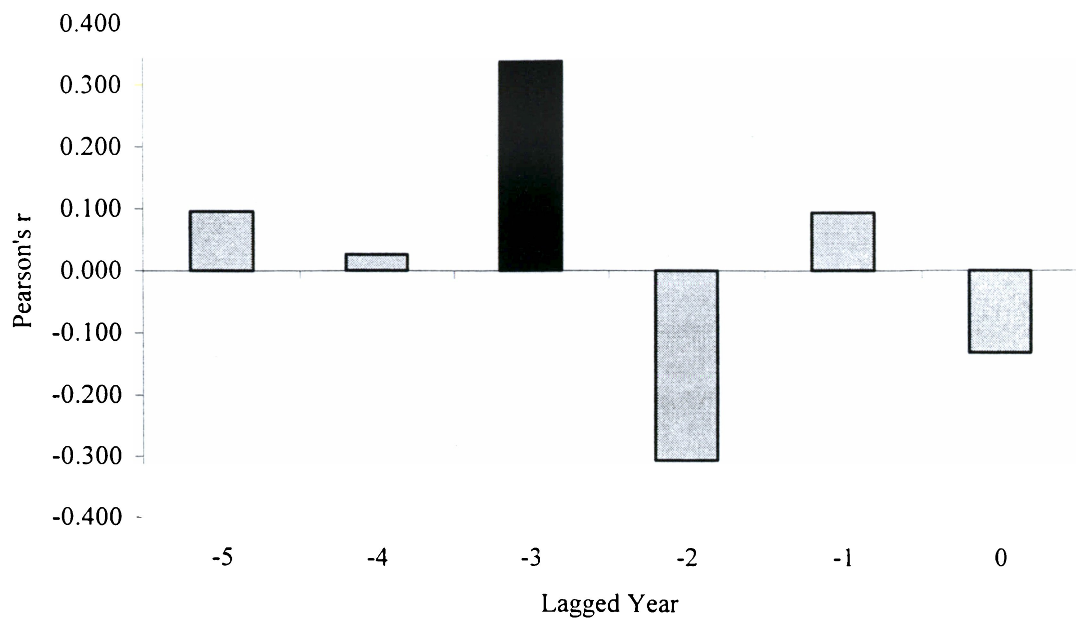

Figure 5-5. Response of the mark-and-recapture index to lagged years of the regional white oak mast reconstruction.

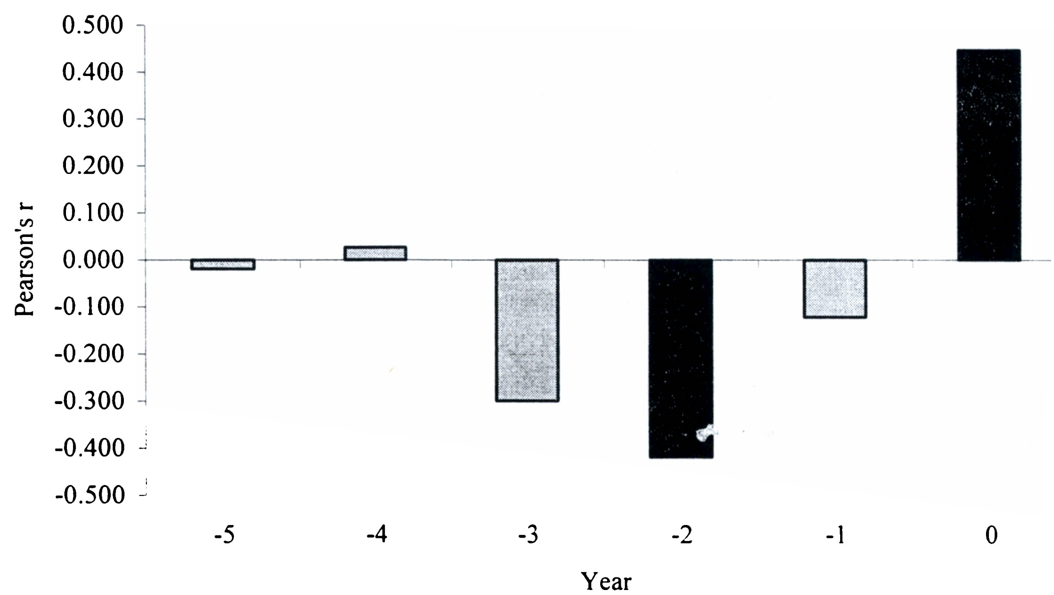

Figure 5-6. Response of the western North Carolina bear index to lagged years of the regional white oak mast reconstruction.

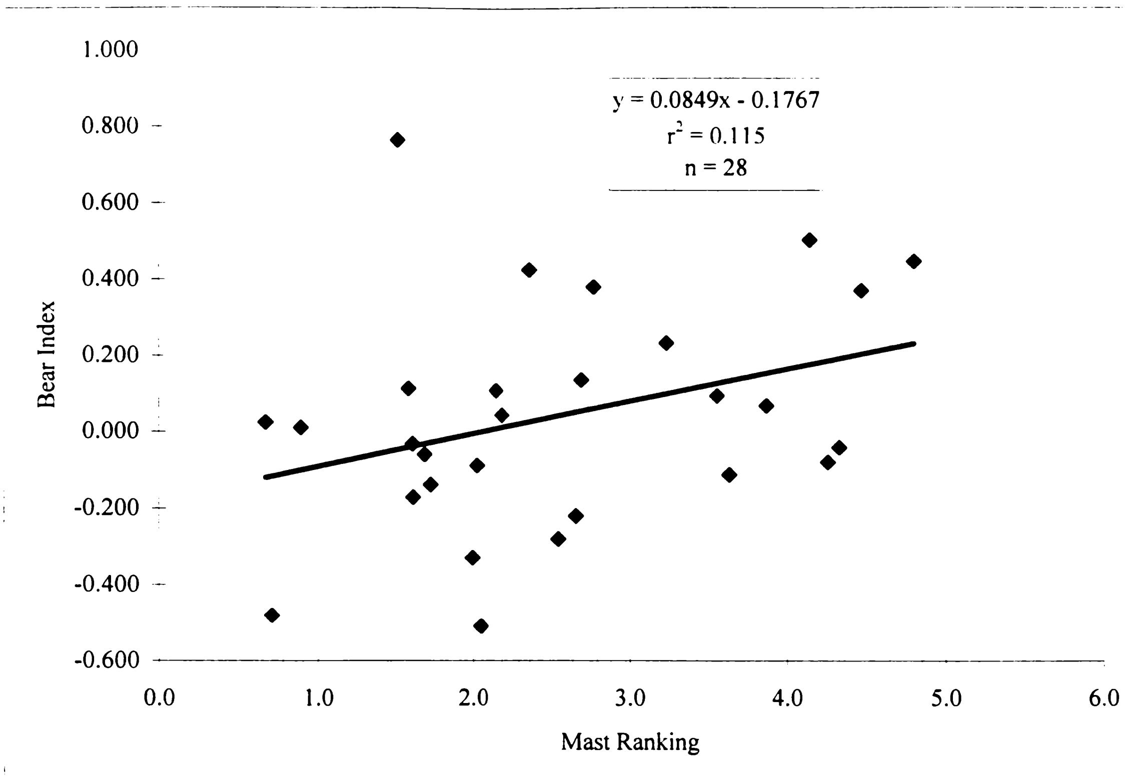

Figure 5-7. Tellico white oak mast reconstruction at year t-3 versus the bear population index.

where y is the bear population index in year t, and x is the reconstructed tree-ring mast value in units of mast ranking. The D-W statistic fell within the acceptable range demonstrating that these time series did not have substantial autocorrelation problems.

SPSS chose a simple linear model only using mast from year t for the western North Carolina bear harvest data analysis, suggesting that some of the variance explained by year t-3 was taken up by year t. Year t alone explained 19.9% of the variance in the standardized bear harvest data (Equation VII; Figure 5-8)) (D-W = 2.071; $p < 0.05$).

$$y_t = 0.5923 * x_t - 1.3654 \qquad \text{[VII]}$$

where y is the bear harvest index in year t, and x is the reconstructed tree-ring mast value.

DISCUSSION

The black bear data used in this analysis are the best data available for the region but may not be ideal. Now that we have a mast reconstruction that extends back 103 years, we are challenged to find comparable wildlife population records. The Tennessee Wildlife Resources Agency has a black bear harvest record for the eastern portion of the state that extends back to 1951. These harvest data also exhibit a positive exponential trend through time, but even when the trend is removed, the effects of changes in management are evident. From 1970 to 1972, the hunting season was never opened for bear because of poor mast years and expected low populations. After this period, a gradual increase occurred in bears harvested from 1973 until 1989, but this period lacks

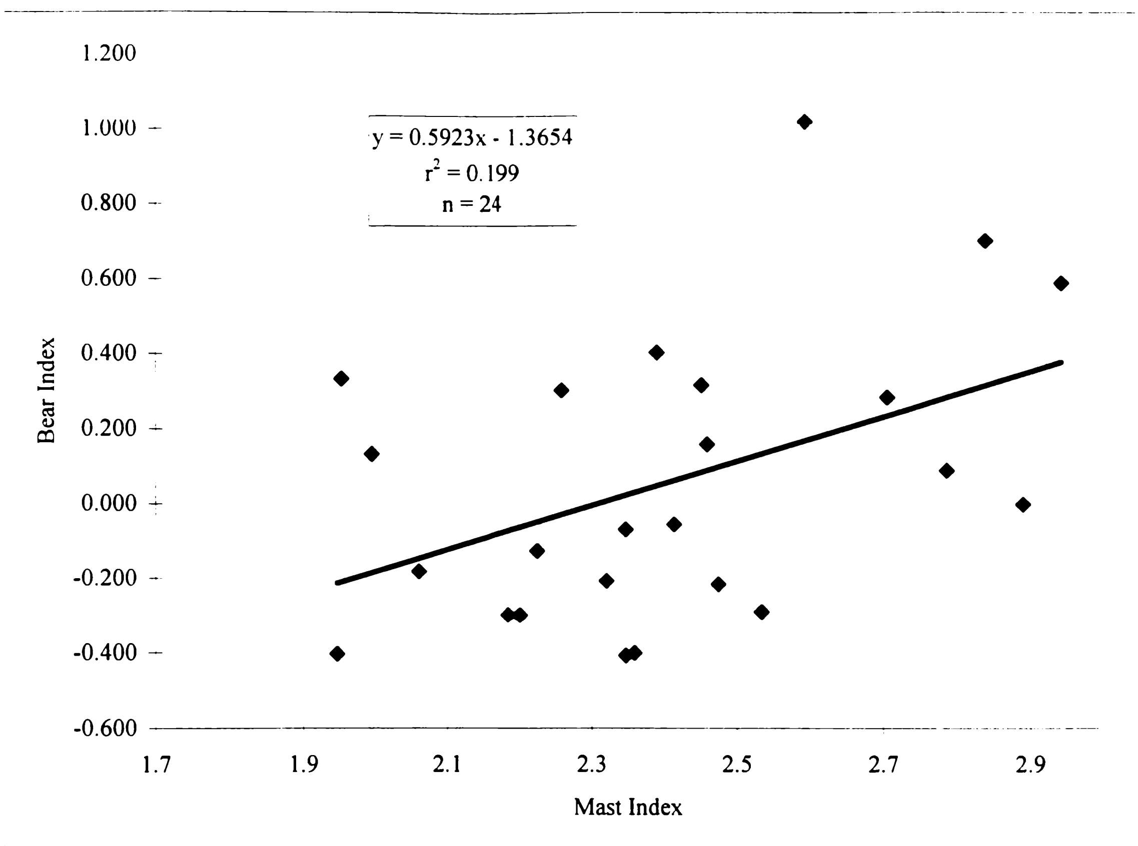

Figure 5-8. Regional white oak mast reconstruction at year t versus the western North Carolina bear harvest data.

the variability of the previous record and may reflect more strict management limits on the numbers of bears harvested each year as well as better record keeping. From 1990 to the present, variability is similar to the 1951 to 1969 record, but the numbers of bears taken are much higher. The trend and inconsistency in the record are likely to obscure any meaningful relationships with long-term mast data. The overall trend can be adjusted for, but the management effects from 1970 until 1989 cannot, so the useful portion of this time series only extends from 1990 to the present. The challenge is to find records that effectively represent the natural variation of the bear populations and extend back more than 30 years. Mast reconstructions can be developed but now we need population data against which to test them.

The mark-and-recapture data provide the most robust estimate of black bear populations in the southern Appalachian region. The significant correlation with mast produced three years prior supports our hypothesis that bear populations in this region are strongly affected by hard mast from white oaks.

The significant correlation of mast at year t with the harvest data supports our hypothesis that bear stay on the landscape longer when food is available so that more hunters encounter bears during the December hunting season. During poor mast years, when food supplies run low, bears will enter their dens early. Hunting regulations prohibit killing a bear that has cubs with it, or a bear that weighs less than 100 pounds. This weight limit generally restricts hunting to bears three or more years old. The significant negative correlation at year t-2 might suggest that high bear survivorship from two years prior produces many bears that are just below the legal hunting limit or may still be with their mothers, making them off limits to legal hunting.

Our study suggests that these mast reconstructions relate to ecosystem processes in predictable ways, demonstrating their potential as environmental records. With longer population records it should be possible to develop more robust models to test mast reconstructions. These tests also need to be expanded to other wildlife species such as the European hog, turkey, and deer. These animals have been shown to depend heavily upon mast, and therefore mast reconstructions may help us gain insight into their past population dynamics.

Chapter 6

Summary and Conclusions

This research has developed and tested a new technique for creating mast reconstructions from tree rings. Past work recognized that a narrow tree ring may be produced in a year of a heavy mast event. To develop and test the validity of mast reconstruction, I examined 55 site-species chronologies from 17 separate sites with up to five species of oak (white, chestnut, northern red, scarlet, and black oak) represented on each site. I analyzed 1,296 cores from 664 individual trees. On average, the site-species chronologies extended back 140 years, with inside dates around AD 1860.

I was successful in completing my first objective, which was to establish the local dendrochronological record from oak trees. All 55 site-species chronologies and all five regional species chronologies produced strong records. The trees I studied are located within closed canopy forest, but nonetheless produced chronologies with surprisingly good series intercorrelations and mean sensitivities. This demonstrates that such trees can be sensitive recorders of a stand-level climate signal. All species proved useful for climate reconstruction except northern red oak. Of the 55 site-species chronologies used in this study, 39 yielded significant models with PDSI and temperature variables ($p < 0.05$). On average these variables explained 15.5% of the variance in the chronologies, with a maximum of 39.2% variance explained. I recommend that further climate reconstructions be conducted using white, chestnut, scarlet, and black oak, even in forest-interior sites, in the southeastern United States. Select sites with bald cypress, juniper, and pine may yield stronger correlations with climate, but the oaks are ubiquitous in the uplands and can be used in locales where these coniferous species are not present. The oaks are also unique in that they record climate as it affects tree growth in forest interiors, where most forest management is focused.

I completed objective 2 by identifying the effect of masting on incremental growth. I compared the incremental growth for the last six years to the mast produced by those individual trees. I found that 7% of the trees correlated significantly with number of acorns they produced each year. When I aggregated all the trees in each stand, still comparing the annual growth of each tree to the mast produced in that year, 25% of the stands correlated significantly. I also examined lagged years to determine if the signal from masting had a stronger lag response. I determined that incremental growth is only suppressed in the single year of mature acorn development. In other words the mast signature is a one year suppression during a heavy mast event. This response is most similar to the effect of drought and emphasizes the importance of a climate subtraction in determining past mast events.

I subtracted climate from the 55 site-species index chronologies and compared the residual chronologies to the longer mast records from the county- and regional-level SWRA data. I was surprised to find that mast did not have a significant effect on tree growth for the majority of sites and species that were sampled. Mast significantly correlated ($p < 0.1$) with the climate residuals at 10.9% of the chronologies. Because of the extensive sample size in this study (17 sites, five species, and 664 trees), I was able to demonstrate the existence of decreased incremental growth in years of heavy mast events on some sites. Without such a large sample from a wide variety of microsite conditions, I probably would not have been able to demonstrate any effect of mast on ring width. This suggests that a trade-off between incremental growth and reproductive effort is usually not evident in southern Appalachian oaks.

The evolved strategies hypothesis predicts that a trade-off between growth and reproductive effort should always be evident. My findings suggest that this tradeoff is seldom measurable, thus bringing this prediction of the theory of evolved strategies into question. The mechanism for producing a narrow tree ring may be more complicated than a simple trade-off between incremental growth and reproductive effort. Two main mechanisms have been suggested for an evolved strategy of masting. One mechanism functions such that after a tree has experienced a heavy mast event, that tree must accumulate sufficient resources before masting can occur again. In this case, the trigger for masting may be a threshold of resource accumulation. Therefore, no unusual drain on the tree occurs in the year of the heavy mast event because the tree has already accumulated the resources needed. Alternatively, if the trees are actually switching resources between incremental growth and reproductive effort, we can expect to always see a reduction in ring width during the year of a heavy mast event. In this case, some environmental or biological trigger starts the masting process in a population of trees, and the trees are forced to switch resources from incremental growth to reproduction, resulting in a reduction in ring width (Table 6-1).

Table 6-1. Hypotheses of masting.

Label	Hypothesis	Prediction
1A	Masting does not occur	No trade-off between incremental growth and reproductive effort will be observed.
1B	Masting is due to environmental resource matching	No trade-off will be observed.
1C	Masting is due to an evolved strategy and depends upon within tree resource accumulation.	If a trade-off does occur it will have a stronger effect on lagged tree growth than the current year of growth.
1D	Masting is due to an evolved strategy and depends upon within tree resource switching.	A trade-off should be observed in all cases.

The effect of masting in incremental growth further depends on whether the trees can actively store carbon and access those stores when needed. If the trees can store moderate amounts of carbon and have some access to this stored resource, the trees would only occasionally demonstrate a reduction in ring width the year of a heavy mast event. Also, the populations that show this reduction should be the ones that are growing in substandard growing conditions and are somewhat limited in resources. If the trees do not store carbon and only perform resource switching, there will necessarily be a reduction in ring width the year of a heavy masting event. Alternately, trees in all populations may store vast quantities of carbon and access that stored reserve whenever it is needed. In this case, no tradeoff would exist because the trees can pull from stored reserves to produce a heavy mast crop and do not have to rely on the current year's photosynthesis (Table 6-2).

A middle possibility also exists. If the trees can store moderate amounts of carbon and have some access to this stored resource, the trees would only occasionally demonstrate a reduction in ring width the year of a heavy mast event. Also, the populations that show this reduction should be ones on sites that offer substandard growing conditions (such as poor soils, low light conditions, or little water availability), leaving the trees somewhat resource-limited. My results suggest that resource switching does occur but that moderate carbon storage is also possible (Figure 6-1). This combination of circumstances would result in a trade-off between incremental growth and reproductive effort on only some sites.

Table 6-2. Hypotheses of recoverable carbon storage.

Label	Hypothesis	Prediction
2A	Trees do not store significant amounts of carbon in recoverable form.	A trade-off between incremental growth and reproductive effort would be evident
2B	Trees store moderate amounts of carbon and can draw it down on occasion.	A trade-off would occasionally be observed.
2C	Trees store large amounts of carbon and draw it down at need.	No trade-off would be observed.

	1A: No masting	1B: Resource Matching	1C: Evolved strategy with resource accumulation	1D: Evolved strategy with resource switching
2A: No carbon storage	No	No	No	Always
2B: Moderate carbon storage	No	No	No	Occasionally
2C: Large carbon storage	No	No	No	No

Figure 6-1. Exploration of the masting hypotheses and carbon storage hypotheses, asking the question: Would a trade-off between incremental growth and reproductive effort be observed under these different hypotheses?

A comparison of sites that do and do not record mast suggests that the trade-off between incremental growth and reproduction might be site specific. I found that trees growing on sites with a moderate northwest-facing slope were more likely to record mast. This may be because, on such sites, biological factors may be more limiting than water availability.

Comparing long mast reconstructions to climate data can test the hypothesis of resource matching. This work has yet to be done, but should be the next step in further research. The monthly climate variables to which tree growth is responding (summer PDSI and proxies for length of growing season) and the variables that are known to affect mast production (spring temperature) are different. Therefore, it should be possible to test for a relationship between climate and masting. If resource matching occurs, growth and masting should respond in unison to climate; if not, masting should react negatively to inclement weather during the spring flowering season (blossoms are aborted or infertile), whereas growth should react positively (less resource competition from maturing fruit).

A comparison of mast reconstructions to climate data would likely produce complex results if the trees are responding to an environmental trigger that synchronizes masting within a population that is not strictly matching resources. In such a case, significant correlations with climate may be found, but those climate variables may act as a trigger rather than contributing to resource allocation. With careful analysis, these two possibilities may be differentiated by examining the timing of a climate correlate. A trigger event would occur two to three years before a heavy mast event in the red oak group and one to two years prior in the white oak group. On the other hand, resource matching should result in climate correlations during year t in the white oak group and year t and year t-1 in the red oak group.

Objective 3 focused on determining a new technique for reconstructing mast events using tree rings. I determined the best technique for creating a mast reconstruction in southern Appalachian oaks (Figure 6-2) and I identified five basic steps that are necessary for mast reconstruction.

1) Crossdate the tree-ring series;

2) Standardize the series with a flexible cubic smoothing spline;

3) Use multiple regression to remove climate;

4) Use simple linear regression between the climate residuals and a known mast record to define a regression equation;

5) Use the regression equation to reconstruct mast beyond the scope of the known mast record.

I developed one regional and five stand-level mast reconstructions that extended back 103 years and explained an average of 32.9% (with a maximum of 46.6%) of the remaining variance after climate was removed. Using both climate and mast, an average of 42.6% (with a maximum of 62.8%) of total variance was explained in these tree-ring chronologies. Scarlet and chestnut oak proved the best species, of the five sampled, for mast reconstruction. Future mast reconstructions in the eastern deciduous forest may be obtainable from these species.

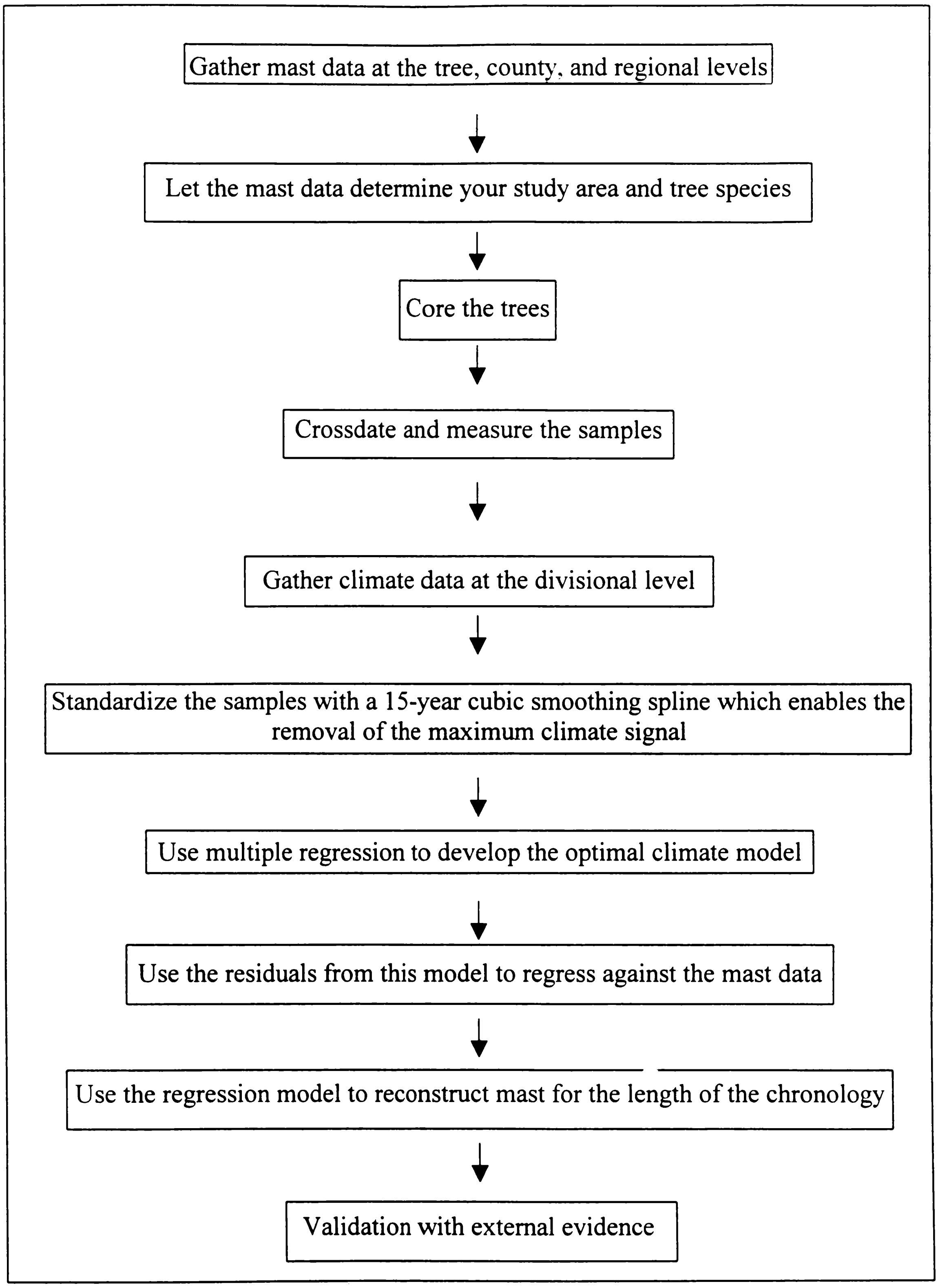

Figure 6-2. Flowchart for Dendromastecology in southern Appalachian oaks.

In fulfilling objective 4, I demonstrated an application of a mast reconstruction by comparing the Tellico white oak and the regional white oak mast reconstructions to bear population estimates from mark-and-recapture data and from western North Carolina bear harvest data, respectively. The Tellico mast reconstruction correlated significantly at year t-3 with the mark-and-recapture index, demonstrating that a heavy mast event can cause an increase in the population of black bears. The regional white oak mast reconstruction had a significant positive correlation with black bear harvest data at year t, suggesting that bears postpone den entrance until later in the year during years with good mast crops. These results demonstrate how dendromastecology can, in principle, inform research into mast-wildlife interactions and population dynamics.

I recommend that other dendrochronologists attempt mast reconstruction on different genera and in different regions. This technique appears to be successful and provides important data for wildlife managers and plant ecologists. Many mast datasets exist around the world and some of these are significantly longer than the records with which I worked. Most of these data are reported only at the stand or regional level, but they provide a starting point for further research. I would like to add, however, that not all mast reconstructions will be successful. It is possible that past researchers have tried mast reconstruction, but because of a lack of significant results, neglected to report their findings. It is important to know whether a strict trade-off between incremental growth and reproductive effort exists in most tree species; therefore, future work in mast reconstruction would be important whether or not all attempts are successful.

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Appendices

Appendix A: Inside dates and date quality of all sampled trees

I tried to locate and sample 931 trees from which the USDA Forest Service collected mast data. I was successful in locating 845 trees and present in this table the inside date of each tree and an indication of the date quality. I took two cores per tree, which provides two attempts to reach the pith. The inside dates that I report are the oldest date I acquired from either core on each tree.

I rated the quality of the inside date by determining how close to center the core reached. A value of "1" means that I hit the pith and this is an exact determination of the tree age at the height that the tree was cored. A value of "2" means that the core did not hit the center of the tree but did pass by it so that curvature in the rings was observed. These cores are generally very close to the pith and the ring width and the curvature of the rings can be used to estimate the number of rings remaining to the pith. I did not make this estimate, however, and only report the date of the innermost ring on the core.

A value of "3" means that according to the diameter at breast height (DBH), the core is long enough to have reached the center of the tree but there is no curvature evident. This can happen when the core approaches the pith directly but did not quite reach the pith. It can also happen when the pith of the tree is off center so that the borer may have reached the geometric center of the tree but not the pith. A value of "4" means that, usually because of rot, the core is much shorter than the radius of the tree and therefore the inside core date is probably far from the actual age of the tree.

I would suggest that inside date quality scores of 1, 2, or 3 could be used as a first approximation of the inside date of the tree, but cores with a dating quality score of 4 should not be used to estimate age of the trees. The lines with data but no inside dates are trees that are in the USFS mast database but could not be relocated and sampled.

The innermost dates reported here will vary from the actual age of the tree by the time it took the tree to grow from germination to the height at which the tree was cored. Furthermore, for inside date quality of higher than 1, the actual age of the tree should include the number of rings between the inside of the core and the actual pith of the tree at that height. My best guess is that most of the inside dates reported here are about 10-15 years after the actual establishment date of the trees. Let me reiterate that the inside dates from cores with a dating quality of 4 are definitely not good estimates of the establishment date of the tree and should not be used as such.

Table A-1. Inside dates of the USFS mast trees and the date quality of those measurements. The diameter at breast height (DBH) was taken when the trees were included in the mast collection sites, which was between 1991 and 1993.

National Forest	***Forest Service Site Name***	***Sample Site Name***	***Tree Number***	***Species***	***DBH (cm)***	***Inside Date***	***Date Quality***
Chattahoochee	Brasstown	Work Center	1	Black Oak	41.4	1927	2
Chattahoochee	Brasstown	Work Center	2	White Oak	49.5	1896	2
Chattahoochee	Brasstown	Work Center	3	Black Oak	64.0	1890	2
Chattahoochee	Brasstown	Work Center	4	White Oak	46.7	1890	2
Chattahoochee	Brasstown	Work Center	5	White Oak	57.4	1805	3
Chattahoochee	Brasstown	Work Center	6	White Oak	71.6	1878	3
Chattahoochee	Brasstown	Work Center	7	Scarlet Oak	55.6	1934	3
Chattahoochee	Brasstown	Work Center	8	Scarlet Oak	36.6	1900	2
Chattahoochee	Brasstown	Work Center	9	Black Oak	55.9	1891	2
Chattahoochee	Brasstown	Work Center	10	Scarlet Oak	41.4	1890	2
Chattahoochee	Brasstown	Work Center	11	White Oak	44.2	1882	2
Chattahoochee	Brasstown	Work Center	12	White Oak	35.1	1914	2
Chattahoochee	Brasstown		15	Northern Red Oak	71.6		
Chattahoochee	Brasstown		16	Northern Red Oak	65.5		
Chattahoochee	Brasstown		17	Northern Red Oak	54.6		
Chattahoochee	Brasstown		18	Northern Red Oak	27.2		
Chattahoochee	Brasstown		19	Northern Red Oak	37.6		
Chattahoochee	Brasstown		20	Chestnut Oak	60.7		
Chattahoochee	Brasstown		21	Northern Red Oak	70.1		
Chattahoochee	Brasstown		22	White Oak			
Chattahoochee	Brasstown		23	Scarlet Oak			
Chattahoochee	Brasstown		24	Black Oak	43.2		
Chattahoochee	Brasstown		25	Chestnut Oak	30.2		
Chattahoochee	Brasstown		26	Scarlet Oak			

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Chattahoochee	Brasstown		27	Chestnut Oak	41.4		
Chattahoochee	Brasstown		28	White Oak	35.1		
Chattahoochee	Brasstown		29	Chestnut Oak	45.2		
Chattahoochee	Brasstown		30	Chestnut Oak	37.8		
Chattahoochee	Brasstown		31	Chestnut Oak	34.5		
Chattahoochee	Brasstown		32	Scarlet Oak	60.2		
Chattahoochee	Brasstown		33	Chestnut Oak	45.7		
Chattahoochee	Cohutta	Cohutta	1	White Oak	34.0	1932	2
Chattahoochee	Cohutta	Cohutta	2	Chestnut Oak	48.3	1940	2
Chattahoochee	Cohutta	Cohutta	3	White Oak	69.3	1929	2
Chattahoochee	Cohutta	Cohutta	4	Black Oak	61.7	1902	2
Chattahoochee	Cohutta	Cohutta	5	Chestnut Oak	63.8	1882	2
Chattahoochee	Cohutta	Cohutta	6	Chestnut Oak	61.2	1903	2
Chattahoochee	Cohutta	Cohutta	7	Chestnut Oak	100.1	1871	4
Chattahoochee	Cohutta	Cohutta	8	Black Oak	52.6	1922	2
Chattahoochee	Cohutta	Cohutta	9	White Oak	27.9	1923	2
Chattahoochee	Cohutta	Cohutta	10	Chestnut Oak	38.9	1926	2
Chattahoochee	Cohutta	Cohutta	11	White Oak	34.8	1926	1
Chattahoochee	Cohutta	Cohutta	12	Black Oak	45.7	1889	2
Chattahoochee	Cohutta	Cohutta	13	White Oak	61.7	1911	2
Chattahoochee	Cohutta	Cohutta	14	White Oak	46.7	1885	2
Chattahoochee	Cohutta	Cohutta	15	Chestnut Oak	37.6	1934	2
Chattahoochee	Cohutta	Cohutta	16	Chestnut Oak	80.8	1911	2
Chattahoochee	Cohutta	Cohutta	17	White Oak	21.6	1933	2
Chattahoochee	Cohutta	Cohutta	18	Scarlet Oak	38.4	1927	1
Chattahoochee	Cohutta	Cohutta	19	Scarlet Oak	62.7	1916	2
Chattahoochee	Cohutta	Cohutta	20	Scarlet Oak	45.7	1906	2
Chattahoochee	Cohutta	Cohutta	21	Scarlet Oak			
Chattahoochee	Cohutta	Cohutta	22	Scarlet Oak	38.1	1924	2
Chattahoochee	Cohutta	Cohutta	23	Scarlet Oak	63.0	1904	2
Chattahoochee	Cohutta	Cohutta	24	Chestnut Oak	24.1	1936	2
Chattahoochee	Cohutta	Cohutta	25	Chestnut Oak	28.2	1947	2
Chattahoochee	Cohutta	Cohutta	26	Chestnut Oak	55.9	1871	2
Chattahoochee	Cohutta	Cohutta	27	Scarlet Oak	27.2	1938	2
Chattahoochee	Cohutta	Cohutta	28	Scarlet Oak	28.2	1942	2
Chattahoochee	Cohutta	Cohutta	29	Scarlet Oak	23.9	1941	2
Chattahoochee	Cohutta	Cohutta	30	Chestnut Oak	70.6	1938	4
Chattahoochee	Tallulah	Tallulah	1	Northern Red Oak	65.8		
Chattahoochee	Tallulah	Tallulah	2	Northern Red Oak	47.0	1940	2
Chattahoochee	Tallulah	Tallulah	3	Northern Red Oak	51.1	1932	2
Chattahoochee	Tallulah	Tallulah	4	Northern Red Oak	46.7	1937	2
Chattahoochee	Tallulah	Tallulah	5	Chestnut Oak	41.4	1932	2
Chattahoochee	Tallulah	Tallulah	6	White Oak	60.2	1810	2
Chattahoochee	Tallulah	Tallulah	7	Chestnut Oak	46.2	1862	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Chattahoochee	Tallulah	Tallulah	8	Chestnut Oak	46.5	1902	2
Chattahoochee	Tallulah	Tallulah	9	Northern Red Oak	36.8	1946	2
Chattahoochee	Tallulah	Tallulah	10	Northern Red Oak	46.0	1933	2
Chattahoochee	Tallulah	Tallulah	11	Chestnut Oak	34.8	1933	2
Chattahoochee	Tallulah	Tallulah	12	Northern Red Oak	43.7	1935	2
Chattahoochee	Tallulah	Tallulah	13	Chestnut Oak	29.7	1936	2
Chattahoochee	Tallulah	Tallulah	14	Northern Red Oak	20.6	1950	2
Chattahoochee	Tallulah	Tallulah	15	Chestnut Oak	31.5	1935	2
Chattahoochee	Tallulah	Tallulah	16	Northern Red Oak	34.5	1933	2
Chattahoochee	Tallulah	Tallulah	17	Northern Red Oak	26.2	1937	2
Chattahoochee	Tallulah	Tallulah	18	Northern Red Oak	59.2	1911	2
Chattahoochee	Tallulah	Tallulah	19	Northern Red Oak	35.1	1938	2
Chattahoochee	Tallulah	Tallulah	20	Northern Red Oak	50.3	1943	2
Chattahoochee	Tallulah	Tallulah	21	Northern Red Oak	80.5	1897	2
Chattahoochee	Tallulah	Tallulah	22	Northern Red Oak	59.7	1936	2
Chattahoochee	Tallulah	Tallulah	23	White Oak	54.9	1868	2
Chattahoochee	Tallulah	Tallulah	24	Black Oak	56.1	1910	2
Chattahoochee	Tallulah	Tallulah	25	Black Oak	60.5	1907	2
Chattahoochee	Tallulah	Tallulah	26	Chestnut Oak	51.6	1915	2
Chattahoochee	Tallulah	Tallulah	27	White Oak	32.8	1907	1
Chattahoochee	Tallulah	Tallulah	28	White Oak	64.0	1888	2
Chattahoochee	Tallulah	Tallulah	29	White Oak	97.0	1880	2
Chattahoochee	Tallulah	Tallulah	30	Northern Red Oak	61.0	1904	2
Chattahoochee	Tallulah	Tallulah	31	White Oak	75.4	1956	2
Chattahoochee	Tallulah	Tallulah	32	White Oak	74.2	1936	2
Chattahoochee	Tallulah	Tallulah	33	Northern Red Oak	75.4	1924	2
Chattahoochee	Tallulah	Tallulah	34	Northern Red Oak	86.9	1932	2
Chattahoochee	Tallulah	Tallulah	35	White Oak	51.8	1861	2
Cherokee	Hiawassee	Hiawassee C	1	Scarlet Oak	46.2	1924	2
Cherokee	Hiawassee	Hiawassee C	2	Scarlet Oak	52.1	1917	2
Cherokee	Hiawassee	Hiawassee C	3	Black Oak	46.0	1923	2
Cherokee	Hiawassee	Hiawassee C	4	Black Oak	54.4	1870	2
Cherokee	Hiawassee	Hiawassee C	5	Black Oak	41.1		
Cherokee	Hiawassee	Hiawassee C	6	Black Oak	33.8	1869	2
Cherokee	Hiawassee	Hiawassee C	7	Chestnut Oak	21.3	1923	2
Cherokee	Hiawassee	Hiawassee C	8	Chestnut Oak	31.5	1923	2
Cherokee	Hiawassee	Hiawassee C	9	Chestnut Oak	18.0	1928	2
Cherokee	Hiawassee	Hiawassee C	10	Chestnut Oak	54.1	1844	2
Cherokee	Hiawassee	Hiawassee C	11	Black Oak	56.1	1875	2
Cherokee	Hiawassee	Hiawassee C	12	Chestnut Oak	28.4	1920	2
Cherokee	Hiawassee	Hiawassee C	13	Chestnut Oak	36.8	1919	2
Cherokee	Hiawassee	Hiawassee C	14	Black Oak	66.8	1878	2
Cherokee	Hiawassee	Hiawassee C	15	Scarlet Oak	25.1	1927	2
Cherokee	Hiawassee	Hiawassee C	16	Chestnut Oak	40.9		

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	Forest Service Site Name	Sample Site Name	Tree Number	Species	DBH (cm)	Inside Date	Date Quality
Cherokee	Hiawassee	Hiawassee C	17	Chestnut Oak	41.7	1923	2
Cherokee	Hiawassee	Hiawassee C	18	Scarlet Oak	27.4	1921	2
Cherokee	Hiawassee	Hiawassee C	19	Scarlet Oak	39.6	1919	2
Cherokee	Hiawassee	Hiawassee C	20	Scarlet Oak	35.8	1920	1
Cherokee	Hiawassee	Hiawassee C	21	Black Oak	35.3	1935	2
Cherokee	Hiawassee	Hiawassee C	22	Scarlet Oak	20.3	1920	2
Cherokee	Hiawassee	Hiawassee C	23	Scarlet Oak	33.5	1928	2
Cherokee	Hiawassee	Hiawassee C	24	Chestnut Oak	41.4	1920	2
Cherokee	Hiawassee	Hiawassee C	25	Chestnut Oak	76.2	1792	2
Cherokee	Hiawassee	Hiawassee C	26	Scarlet Oak	69.9		
Cherokee	Hiawassee	Hiawassee C	27	Scarlet Oak	64.3	1898	2
Cherokee	Hiawassee	Hiawassee C	28	Black Oak	61.0	1829	2
Cherokee	Hiawassee	Hiawassee C	29	Black Oak	75.9	1905	2
Cherokee	Hiawassee	Hiawassee C	30	Scarlet Oak	44.7		
Cherokee	Hiawassee	Hiawassee C	31	Scarlet Oak	64.8	1902	3
Cherokee	Hiawassee	Hiawassee C	32	Black Oak	67.1	1870	4
Cherokee	Hiawassee	Hiawassee C	33	Chestnut Oak	50.0	1917	2
Cherokee	Hiawassee	Hiawassee B	34	White Oak	49.3	1884	2
Cherokee	Hiawassee	Hiawassee B	35	White Oak	30.0	1921	2
Cherokee	Hiawassee	Hiawassee B	36	White Oak	54.4	1904	2
Cherokee	Hiawassee	Hiawassee B	37	White Oak	49.8	1907	2
Cherokee	Hiawassee	Hiawassee B	38	White Oak	32.5	1900	2
Cherokee	Hiawassee	Hiawassee B	39	White Oak	61.7	1902	2
Cherokee	Hiawassee	Hiawassee B	40	White Oak	27.2	1916	2
Cherokee	Hiawassee	Hiawassee B	41	White Oak	39.4	1923	2
Cherokee	Hiawassee	Hiawassee B	42	White Oak	27.2	1898	2
Cherokee	Hiawassee	Hiawassee B	43	White Oak	27.4	1916	2
Cherokee	Hiawassee	Hiawassee D	44	Chestnut Oak	45.0		
Cherokee	Hiawassee	Hiawassee D	45	Black Oak	25.7	1929	2
Cherokee	Hiawassee	Hiawassee D	46	White Oak	63.8	1939	4
Cherokee	Hiawassee	Hiawassee D	47	White Oak	63.5	1873	2
Cherokee	Hiawassee	Hiawassee D	48	Black Oak	22.9		
Cherokee	Hiawassee	Hiawassee D	49	Black Oak	22.9		
Cherokee	Hiawassee	Hiawassee D	50	Scarlet Oak	75.2	1898	2
Cherokee	Hiawassee	Hiawassee D	51	Chestnut Oak	59.9	1887	2
Cherokee	Hiawassee	Hiawassee D	52	White Oak	73.7	1805	1
Cherokee	Hiawassee	Hiawassee D	53	Chestnut Oak	76.2	1925	2
Cherokee	Hiawassee	Hiawassee D	54	Black Oak	81.3	1879	2
Cherokee	Hiawassee	Hiawassee D	55	Black Oak	82.6	1847	3
Cherokee	Hiawassee	Hiawassee D	56	Chestnut Oak	68.6	1856	2
Cherokee	Hiawassee	Hiawassee D	57	Chestnut Oak	82.6		
Cherokee	Hiawassee	Hiawassee D	58	Chestnut Oak	66.0		
Cherokee	Hiawassee	Hiawassee D	59	White Oak	76.2		
Cherokee	Hiawassee	Hiawassee D	60	White Oak	105.4		

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Cherokee	Hiawassee	Hiawassee A	61	Scarlet Oak	77.5	1909	2
Cherokee	Hiawassee	Hiawassee A	62	Scarlet Oak	80.8	1916	4
Cherokee	Nolichucky	Burnett Gap	1	Northern Red Oak	80.0	1893	2
Cherokee	Nolichucky	Burnett Gap	2	White Oak	80.8	1779	3
Cherokee	Nolichucky	Burnett Gap	3	White Oak	85.9		
Cherokee	Nolichucky	Burnett Gap	4	Black Oak	76.7		
Cherokee	Nolichucky	Burnett Gap	5	Northern Red Oak	16.3		
Cherokee	Nolichucky	Burnett Gap	6	Northern Red Oak	27.2		
Cherokee	Nolichucky	Burnett Gap	7	Black Oak	22.1		
Cherokee	Nolichucky	Burnett Gap	8	Black Oak	23.9		
Cherokee	Nolichucky	Burnett Gap	9	Black Oak	27.7		
Cherokee	Nolichucky	Burnett Gap	10	Northern Red Oak	65.3	1890	2
Cherokee	Nolichucky	Burnett Gap	11	Northern Red Oak	62.5	1901	2
Cherokee	Nolichucky	Burnett Gap	12	White Oak	75.7	1828	2
Cherokee	Nolichucky	Burnett Gap	13	Scarlet Oak	20.3		
Cherokee	Nolichucky	Burnett Gap	14	Scarlet Oak	20.1		
Cherokee	Nolichucky	Burnett Gap	15	Scarlet Oak	20.8		
Cherokee	Nolichucky	Burnett Gap	16	Black Oak	46.5		
Cherokee	Nolichucky	Burnett Gap	17	Northern Red Oak	24.4		
Cherokee	Nolichucky	Burnett Gap	18	Northern Red Oak	52.6	1940	2
Cherokee	Nolichucky	Burnett Gap	19	Northern Red Oak	67.1	1925	2
Cherokee	Nolichucky	Burnett Gap	20	Northern Red Oak	53.8	1922	2
Cherokee	Nolichucky	Burnett Gap	21	White Oak	23.6		
Cherokee	Nolichucky	Burnett Gap	22	Chestnut Oak	53.8		
Cherokee	Nolichucky	Burnett Gap	23	Black Oak	39.4	1922	2
Cherokee	Nolichucky	Burnett Gap	24	Black Oak	28.4		
Cherokee	Nolichucky	Burnett Gap	25	Northern Red Oak	36.1	1939	2
Cherokee	Nolichucky	Burnett Gap	26	Northern Red Oak	57.2	1932	2
Cherokee	Nolichucky	Burnett Gap	27	White Oak	65.0	1937	4
Cherokee	Nolichucky	Burnett Gap	28	Black Oak	36.8		
Cherokee	Nolichucky	Burnett Gap	29	White Oak	19.1	1923	2
Cherokee	Nolichucky	Burnett Gap	30	White Oak	23.9		
Cherokee	Nolichucky	Burnett Gap	31	Black Oak	62.0	1923	2
Cherokee	Nolichucky	Burnett Gap	32	Chestnut Oak	49.8		
Cherokee	Nolichucky	Burnett Gap	33	Chestnut Oak	63.8		
Cherokee	Nolichucky	Burnett Gap	34	Chestnut Oak	23.6		
Cherokee	Nolichucky	Burnett Gap	35	White Oak	30.5		
Cherokee	Nolichucky	Burnett Gap	36	Scarlet Oak	40.9	1917	1
Cherokee	Nolichucky	Burnett Gap	37	Scarlet Oak	41.1	1923	2
Cherokee	Nolichucky	Burnett Gap	38	Scarlet Oak	39.1	1887	2
Cherokee	Nolichucky	Burnett Gap	39	Scarlet Oak	72.6	1893	3
Cherokee	Nolichucky	Burnett Gap	40	Scarlet Oak	58.4	1898	2
Cherokee	Nolichucky	Burnett Gap	41	Scarlet Oak	67.3	1891	2
Cherokee	Nolichucky	Burnett Gap	42	Scarlet Oak	56.6	1898	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Cherokee	Nolichucky	Burnett Gap	43	Chestnut Oak	23.1	1934	2
Cherokee	Nolichucky	Burnett Gap	44	Scarlet Oak	51.1	1895	1
Cherokee	Nolichucky	Burnett Gap	45	White Oak	42.7	1891	1
Cherokee	Nolichucky	Burnett Gap	46	Chestnut Oak	31.0	1974	4
Cherokee	Nolichucky	Burnett Gap	47	Chestnut Oak	35.1	1885	1
Cherokee	Nolichucky	Burnett Gap	48	Chestnut Oak	24.1	1933	2
Cherokee	Nolichucky	Burnett Gap	49	Chestnut Oak	64.8	1892	4
Cherokee	Nolichucky	Burnett Gap	50	Chestnut Oak	47.8	1920	2
Cherokee	Nolichucky	Burnett Gap	51	Black Oak	68.6	1876	1
Cherokee	Nolichucky	Burnett Gap	52	Chestnut Oak	41.9	1919	2
Cherokee	Nolichucky	Burnett Gap	53	Chestnut Oak	37.6	1935	2
Cherokee	Nolichucky	Burnett Gap	54	White Oak	46.0	1922	2
Cherokee	Nolichucky	Burnett Gap	55	White Oak	36.1	1909	2
Cherokee	Nolichucky	Burnett Gap	56	White Oak	55.9	1928	2
Cherokee	Nolichucky	Burnett Gap	57	Black Oak	74.2	1847	2
Cherokee	Nolichucky	Burnett Gap	58	Black Oak	71.4	1870	2
Cherokee	Nolichucky	Burnett Gap	59	Black Oak	54.9	1891	2
Cherokee	Nolichucky	Burnett Gap	60	Scarlet Oak	57.7	1915	2
Cherokee	Nolichucky	Burnett Gap	61	Black Oak	46.0	1898	2
Cherokee	Nolichucky	Burnett Gap	62	Scarlet Oak	73.7	1907	2
Cherokee	Nolichucky	Burnett Gap	63	White Oak	64.8	1846	2
Cherokee	Nolichucky	Burnett Gap	64	White Oak	54.6	1906	2
Cherokee	Nolichucky	Burnett Gap	65	Black Oak	82.6	1885	3
Cherokee	Nolichucky	Burnett Gap	66	Scarlet Oak	75.2	1936	3
Cherokee	Nolichucky	Burnett Gap	67	White Oak	66.5	1899	3
Cherokee	Nolichucky	Burnett Gap	68	Northern Red Oak	35.6	1913	1
Cherokee	Nolichucky	Burnett Gap	69	Northern Red Oak	35.3	1928	2
Cherokee	Nolichucky	Burnett Gap	70	Northern Red Oak	76.7	1917	2
Cherokee	Nolichucky	Burnett Gap	71	Chestnut Oak	75.4	1902	3
Cherokee	Tellico	Tellico	1	Black Oak	39.1	1886	1
Cherokee	Tellico	Tellico	2	Northern Red Oak	75.9	1901	2
Cherokee	Tellico	Tellico	3	Chestnut Oak	48.8	1928	2
Cherokee	Tellico	Tellico	4	Northern Red Oak	44.5	1967	4
Cherokee	Tellico	Tellico	5	Northern Red Oak	45.2	1946	4
Cherokee	Tellico	Tellico	6	Chestnut Oak	57.7	1862	2
Cherokee	Tellico	Tellico	7	Northern Red Oak	25.9	1910	1
Cherokee	Tellico	Tellico	8	Northern Red Oak	30.7	1931	1
Cherokee	Tellico	Tellico	9	Northern Red Oak	39.4	1940	2
Cherokee	Tellico	Tellico	10	Northern Red Oak	34.8	1940	2
Cherokee	Tellico	Tellico	11	Northern Red Oak	35.6	1929	1
Cherokee	Tellico	Tellico	12	Northern Red Oak	59.2	1854	1
Cherokee	Tellico	Tellico	13	Northern Red Oak	59.9	1929	4
Cherokee	Tellico	Tellico	14	Chestnut Oak	47.2	1854	2
Cherokee	Tellico	Tellico	15	Chestnut Oak	42.7	1861	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Cherokee	Tellico	Tellico	16	Chestnut Oak	44.7	1854	2
Cherokee	Tellico	Tellico	17	Chestnut Oak	86.1	1854	4
Cherokee	Tellico	Tellico	18	Northern Red Oak	47.8	1934	2
Cherokee	Tellico	Tellico	19	Black Oak	38.4	1929	1
Cherokee	Tellico	Tellico	20	Northern Red Oak	45.2	1938	2
Cherokee	Tellico	Tellico	21	Black Oak	43.4	1925	1
Cherokee	Tellico	Tellico	22	Black Oak	26.9	1931	1
Cherokee	Tellico	Tellico	23	Chestnut Oak	25.4	1932	2
Cherokee	Tellico	Tellico	24	Chestnut Oak	26.7	1926	2
Cherokee	Tellico	Tellico	25	Chestnut Oak	26.9	1925	1
Cherokee	Tellico	Tellico	26	Chestnut Oak	47.5	1937	2
Cherokee	Tellico	Tellico	27	Black Oak	52.8	1917	2
Cherokee	Tellico	Tellico	28	Black Oak	25.4	1938	2
Cherokee	Tellico	Tellico	29	Black Oak	35.6	1934	2
Cherokee	Tellico	Tellico	30	Black Oak	48.3	1906	2
Cherokee	Tellico	Tellico	31	Northern Red Oak	42.9	1913	2
Cherokee	Tellico	Tellico	32	Black Oak	38.9	1904	2
Cherokee	Tellico	Tellico	33	Chestnut Oak	59.2	1910	2
Cherokee	Tellico	Tellico	34	Black Oak	45.0	1868	2
Cherokee	Tellico	Tellico	35	White Oak	84.8	1956	4
Cherokee	Tellico	Tellico	36	Northern Red Oak	47.0	1929	1
Cherokee	Tellico	Tellico	37	Black Oak	41.4	1929	2
Cherokee	Tellico	Tellico	38	Chestnut Oak	47.5	1909	1
Cherokee	Tellico	Tellico	39	Chestnut Oak	39.9	1931	1
Cherokee	Tellico	Tellico	40	Chestnut Oak	32.8	1934	2
Cherokee	Tellico	Tellico	41	Black Oak	27.9	1919	2
Cherokee	Tellico	Tellico	42	White Oak	40.1	1916	2
Cherokee	Tellico	Tellico	43	Black Oak	42.2	1916	2
Cherokee	Tellico	Tellico	44	Chestnut Oak	30.0		
Cherokee	Tellico	Tellico	45	Black Oak	54.4	1882	2
Cherokee	Tellico	Tellico	46	Black Oak	36.6	1920	2
Cherokee	Tellico	Tellico	47	White Oak	23.9	1932	2
Cherokee	Tellico	Tellico	48	White Oak	26.2	1932	2
Cherokee	Tellico	Tellico	49	White Oak	49.0	1874	2
Cherokee	Tellico	Tellico	50	Black Oak	63.2	1893	4
Cherokee	Tellico	Tellico	51	Black Oak	31.8	1925	1
Cherokee	Tellico	Tellico	52	Chestnut Oak	37.1	1930	2
Cherokee	Tellico	Tellico	53	Chestnut Oak	31.8	1932	2
Cherokee	Tellico	Tellico	54	Chestnut Oak	37.1	1931	2
Cherokee	Tellico	Tellico	55	Scarlet Oak	38.1	1937	2
Cherokee	Tellico	Tellico	56	Black Oak	33.5	1933	2
Cherokee	Tellico	Tellico	57	Scarlet Oak	28.4	1932	1
Cherokee	Tellico	Tellico	58	Scarlet Oak	41.1	1928	1
Cherokee	Tellico	Tellico	59	Scarlet Oak	36.6	1934	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Cherokee	Tellico	Tellico	60	Northern Red Oak	22.9	1938	2
Cherokee	Tellico	Tellico	61	Northern Red Oak	31.0	1931	2
Cherokee	Tellico	Tellico	62	Northern Red Oak	28.2	1938	2
Cherokee	Tellico	Tellico	63	Northern Red Oak	42.2	1938	2
Cherokee	Tellico	Tellico	64	Scarlet Oak	40.6		
Cherokee	Tellico	Tellico	65	Scarlet Oak	48.8	1914	2
Cherokee	Tellico	Tellico	66	Scarlet Oak	40.6	1905	1
Cherokee	Tellico	Tellico	67	Scarlet Oak	46.7	1911	2
Cherokee	Tellico	Tellico	68	Scarlet Oak	53.3	1932	2
Cherokee	Tellico	Tellico	69	Scarlet Oak	45.7		
Cherokee	Tellico	Tellico	70	Scarlet Oak	53.1	1931	2
Cherokee	Tellico	Tellico	71	Scarlet Oak	54.4	1924	2
Cherokee	Tellico	Tellico	72	Scarlet Oak	31.8	1924	1
Cherokee	Tellico	Tellico	73	Scarlet Oak	24.6	1929	1
Cherokee	Tellico	Tellico	74	White Oak	27.2	1933	2
Cherokee	Tellico	Tellico	75	Scarlet Oak	43.7	1932	2
Cherokee	Tellico	Tellico	76	Scarlet Oak	31.8	1929	2
Cherokee	Tellico	Tellico	77	White Oak	31.0	1924	1
Cherokee	Tellico	Tellico	78	Scarlet Oak	31.0	1931	1
Cherokee	Tellico	Tellico	79	Scarlet Oak	26.4	1935	2
Cherokee	Tellico	Tellico	80	White Oak	44.5	1838	2
Cherokee	Tellico	Tellico	81	White Oak	43.7	1839	2
Cherokee	Tellico	Tellico	82	White Oak	33.8	1839	2
Cherokee	Tellico	Tellico	83	White Oak	36.3	1844	2
Cherokee	Tellico	Tellico	84	White Oak	55.6	1842	1
Cherokee	Tellico	Tellico	85	White Oak	40.9	1851	1
Cherokee	Tellico	Tellico	86	White Oak	70.9	1845	4
Cherokee	Tellico	Tellico	87	White Oak	46.5	1890	2
Cherokee	Tellico	Tellico	88	White Oak	47.8	1911	2
Cherokee	Tellico	Tellico	89	White Oak	33.8	1833	2
Cherokee	Tellico	Tellico	90	White Oak	31.8	1846	2
Cherokee	Unaka	Jackson Farm	1	White Oak	26.2	1953	2
Cherokee	Unaka	Jackson Farm	2	White Oak	32.5	1953	2
Cherokee	Unaka	Jackson Farm	3	Black Oak	38.4	1952	2
Cherokee	Unaka	Jackson Farm	4	Black Oak	40.4	1955	2
Cherokee	Unaka	Jackson Farm	5	Scarlet Oak	55.4	1960	3
Cherokee	Unaka	Jackson Farm	6	White Oak	36.1	1954	2
Cherokee	Unaka	Jackson Farm	7	White Oak	28.7	1957	2
Cherokee	Unaka	Jackson Farm	8	Northern Red Oak	42.7	1950	1
Cherokee	Unaka	Jackson Farm	9	White Oak	27.7	1956	2
Cherokee	Unaka	Jackson Farm	10	White Oak	44.5	1951	2
Cherokee	Unaka	Jackson Farm	11	Northern Red Oak	55.6	1964	2
Cherokee	Unaka	Jackson Farm	12	Black Oak	46.2	1952	2
Cherokee	Unaka	Jackson Farm	13	Northern Red Oak	33.0	1952	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	Forest Service Site Name	Sample Site Name	Tree Number	Species	DBH (cm)	Inside Date	Date Quality
Cherokee	Unaka	Jackson Farm	14	Black Oak	30.2	1951	1
Cherokee	Unaka	Jackson Farm	15	Black Oak	53.6	1960	2
Cherokee	Unaka	Jackson Farm	16	Black Oak	46.7	1951	1
Cherokee	Unaka	Jackson Farm	17	Black Oak	58.4	1953	2
Cherokee	Unaka	Jackson Farm	18	White Oak	17.5	1951	1
Cherokee	Unaka	Jackson Farm	19	Chestnut Oak	33.8	1953	2
Cherokee	Unaka	Jackson Farm	20	Scarlet Oak	46.7	1952	2
Cherokee	Unaka	Jackson Farm	21	Black Oak	25.9	1953	1
Cherokee	Unaka	Jackson Farm	22	Scarlet Oak	31.8	1946	2
Cherokee	Unaka	Jackson Farm	23	Chestnut Oak	39.9	1936	2
Cherokee	Unaka	Jackson Farm	24	Chestnut Oak	50.3	1934	1
Cherokee	Unaka	Jackson Farm	25	Chestnut Oak	27.2	1941	2
Cherokee	Unaka	Jackson Farm	26	Chestnut Oak	33.3	1955	2
Cherokee	Unaka	Jackson Farm	27	White Oak	51.1	1935	1
Cherokee	Unaka	Jackson Farm	28	Chestnut Oak	48.8	1935	2
Cherokee	Unaka	Jackson Farm	29	Northern Red Oak	35.3	1950	2
Cherokee	Unaka	Jackson Farm	30	Chestnut Oak	47.5	1933	2
Cherokee	Unaka	Jackson Farm	31	Chestnut Oak	58.4	1949	3
Cherokee	Unaka	Jackson Farm	32	Chestnut Oak	71.9	1943	4
Cherokee	Unaka	Jackson Farm	33	Chestnut Oak	21.6	1926	2
Cherokee	Unaka	Jackson Farm	34	Chestnut Oak	26.4	1941	1
Cherokee	Unaka	Jackson Farm	35	Scarlet Oak	42.2	1948	2
Cherokee	Unaka	Jackson Farm	36	Scarlet Oak	32.3	1947	2
Cherokee	Unaka	Jackson Farm	37	Scarlet Oak	45.0	1954	2
Cherokee	Unaka	Jackson Farm	38	Scarlet Oak	17.0	1960	2
Cherokee	Unaka	Jackson Farm	39	Scarlet Oak	26.7	1967	2
Cherokee	Unaka	Jackson Farm	40	Black Oak	17.0	1958	2
Cherokee	Unaka	Jackson Farm	41	Black Oak	26.9	1959	2
Cherokee	Unaka	Jackson Farm	42	Scarlet Oak	66.8	1863	2
Cherokee	Unaka	Jackson Farm	43	White Oak	52.6	1931	2
Cherokee	Unaka	Jackson Farm	44	Scarlet Oak	66.8	1960	2
Cherokee	Unaka	Jackson Farm	45	White Oak	71.4	1933	2
Cherokee	Unaka	Jackson Farm	46	Northern Red Oak	49.3	1935	1
Cherokee	Unaka	Jackson Farm	47	Northern Red Oak	56.9	1942	2
Cherokee	Unaka	Jackson Farm	48	White Oak	81.5	1933	4
Cherokee	Unaka	Jackson Farm	49	White Oak	61.2	1879	2
Cherokee	Unaka	Jackson Farm	50	White Oak	60.5		
Cherokee	Unaka	Jackson Farm	51	Black Oak	64.0	1937	2
Cherokee	Unaka	Jackson Farm	52	Northern Red Oak	101.6	1929	3
Cherokee	Unaka	Jackson Farm	53	Chestnut Oak	80.0	1877	3
Cherokee	Unaka	Jackson Farm	54	Chestnut Oak	106.2	1942	4
Cherokee	Unaka	Jackson Farm	55	Scarlet Oak	58.4	1932	2
Cherokee	Unaka	Jackson Farm	56	Northern Red Oak	55.4	1947	2
Cherokee	Unaka	Jackson Farm	57	Northern Red Oak	23.1	1934	1

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Cherokee	Unaka	Jackson Farm	58	Northern Red Oak	25.4	1940	2
Cherokee	Unaka	Jackson Farm	59	Black Oak	50.0	1932	2
Cherokee	Unaka	Jackson Farm	60	White Oak	49.0	1934	2
Cherokee	Unaka	Jackson Farm	61	Black Oak	51.6	1922	1
Cherokee	Unaka	Jackson Farm	62	Northern Red Oak	54.4	1950	2
Cherokee	Unaka	Jackson Farm	63	Scarlet Oak	55.4	1938	2
Cherokee	Unaka	Jackson Farm	64	Northern Red Oak	17.5	1940	2
Cherokee	Unaka	Jackson Farm	65	White Oak	80.0	1910	3
Cherokee	Unaka	Jackson Farm	66	Northern Red Oak	133.4	1851	3
Cherokee	Unaka	Jackson Farm	67	Northern Red Oak	86.4	1925	3
Cherokee	Unaka	Jackson Farm	68	Northern Red Oak	88.4	1915	2
Cherokee	Unaka	Jackson Farm	69	Northern Red Oak	63.0	1903	2
Cherokee	Unaka	Jackson Farm	70	Northern Red Oak	62.0	1922	2
Cherokee	Unaka	Jackson Farm	71	Northern Red Oak	66.3	1863	2
Cherokee	Unaka	Jackson Farm	72	Chestnut Oak	67.8	1861	2
Cherokee	Watauga	Watauga	1	White Oak	20.6	1967	2
Cherokee	Watauga	Watauga	2	White Oak	19.1	1971	2
Cherokee	Watauga	Watauga	3	White Oak	27.2	1930	2
Cherokee	Watauga	Watauga	4	White Oak	21.1	1967	2
Cherokee	Watauga	Watauga	5	White Oak	23.6	1916	2
Cherokee	Watauga	Watauga	6	White Oak	19.1	1968	1
Cherokee	Watauga	Watauga	7	White Oak	23.4	1967	2
Cherokee	Watauga	Watauga	8	White Oak	19.1	1967	1
Cherokee	Watauga	Watauga	9	White Oak	24.9	1913	1
Cherokee	Watauga	Watauga	10	White Oak	19.1	1967	1
Cherokee	Watauga	Watauga	11	White Oak	23.6	1967	4
Cherokee	Watauga	Watauga	12	White Oak	18.0	1969	2
Cherokee	Watauga	Watauga	13	White Oak	15.7	1967	1
Cherokee	Watauga	Watauga	14	White Oak	16.3	1968	2
Cherokee	Watauga	Watauga	15	White Oak	16.5	1967	1
Cherokee	Watauga	Watauga	16	White Oak	18.8	1968	1
Cherokee	Watauga	Watauga	17	White Oak	13.7	1967	2
Cherokee	Watauga	Watauga	18	White Oak	24.9	1971	2
Cherokee	Watauga	Watauga	19	White Oak	18.5	1969	2
Cherokee	Watauga	Watauga	20	White Oak	17.8	1970	2
Cherokee	Watauga	Watauga	21	White Oak	17.0	1967	2
Cherokee	Watauga	Watauga	22	White Oak	29.5	1915	1
Cherokee	Watauga	Watauga	23	White Oak	33.3	1919	2
Cherokee	Watauga	Watauga	24	White Oak	32.0	1901	2
Cherokee	Watauga	Watauga	25	White Oak	35.8	1888	1
Cherokee	Watauga	Watauga	26	White Oak	42.7	1846	2
Cherokee	Watauga	Watauga	27	White Oak	28.4	1905	2
Cherokee	Watauga	Watauga	28	White Oak	47.5	1881	2
Cherokee	Watauga	Watauga	29	White Oak	30.5	1880	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Cherokee	Watauga	Watauga	30	White Oak	31.2	1893	2
Cherokee	Watauga	Watauga	31	White Oak	38.1	1910	2
Cherokee	Watauga	Watauga	32	White Oak	40.4	1879	2
Cherokee	Watauga	Watauga	33	White Oak	51.3	1871	2
Cherokee	Watauga	Watauga	34	White Oak	44.5	1901	1
Cherokee	Watauga	Watauga	35	White Oak	83.3	1820	3
Cherokee	Watauga	Watauga	36	Black Oak	19.8	1967	1
Cherokee	Watauga	Watauga	37	Black Oak	24.9	1968	2
Cherokee	Watauga	Watauga	38	Black Oak	49.5	1903	2
Cherokee	Watauga	Watauga	39	Scarlet Oak	19.3	1966	1
Cherokee	Watauga	Watauga	40	Black Oak	53.8	1911	2
Cherokee	Watauga	Watauga	41	Scarlet Oak	23.6	1968	2
Cherokee	Watauga	Watauga	42	Black Oak	46.0	1901	2
Cherokee	Watauga	Watauga	43	Scarlet Oak	24.1	1969	2
Cherokee	Watauga	Watauga	44	Black Oak	46.5	1915	2
Cherokee	Watauga	Watauga	45	Scarlet Oak	21.3	1965	2
Cherokee	Watauga	Watauga	46	Black Oak	59.7	1901	2
Cherokee	Watauga	Watauga	47	Scarlet Oak	23.4	1971	2
Cherokee	Watauga	Watauga	48	Black Oak	47.8	1909	2
Cherokee	Watauga	Watauga	49	Scarlet Oak	20.8	1970	2
Cherokee	Watauga	Watauga	50	Black Oak	45.7	1904	2
Cherokee	Watauga	Watauga	51	Scarlet Oak	25.7	1968	1
Cherokee	Watauga	Watauga	52	Scarlet Oak	21.6	1968	2
Cherokee	Watauga	Watauga	53	Northern Red Oak	20.6	1969	2
Cherokee	Watauga	Watauga	54	Scarlet Oak	24.6	1975	2
Cherokee	Watauga	Watauga	55	Chestnut Oak	23.9	1969	2
Cherokee	Watauga	Watauga	56	Northern Red Oak	57.4	1906	2
Cherokee	Watauga	Watauga	57	Scarlet Oak	16.8	1977	2
Cherokee	Watauga	Watauga	58	Chestnut Oak	20.6	1966	2
Cherokee	Watauga	Watauga	59	Northern Red Oak	50.8	1917	2
Cherokee	Watauga	Watauga	60	Scarlet Oak	22.9	1971	2
Cherokee	Watauga	Watauga	61	Chestnut Oak	25.4	1967	1
Cherokee	Watauga	Watauga	62	Northern Red Oak	52.3	1906	2
Cherokee	Watauga	Watauga	63	Scarlet Oak	29.2	1979	1
Cherokee	Watauga	Watauga	64	Chestnut Oak	19.8	1968	2
Cherokee	Watauga	Watauga	65	Northern Red Oak	54.6	1939	3
Cherokee	Watauga	Watauga	66	Scarlet Oak	18.3	1962	1
Cherokee	Watauga	Watauga	67	Chestnut Oak	25.4	1968	2
Cherokee	Watauga	Watauga	68	Northern Red Oak	76.2	1901	2
Cherokee	Watauga	Watauga	69	Scarlet Oak	21.6	1971	2
Cherokee	Watauga	Watauga	70	Chestnut Oak	18.3	1968	1
Cherokee	Watauga	Watauga	71	Northern Red Oak	44.7	1900	2
Cherokee	Watauga	Watauga	72	Scarlet Oak	16.3	1976	2
Cherokee	Watauga	Watauga	73	Chestnut Oak	25.1	1970	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Cherokee	Watauga	Watauga	74	Northern Red Oak	45.7	1911	2
Cherokee	Watauga	Watauga	75	Scarlet Oak	18.8	1971	2
Cherokee	Watauga	Watauga	76	Chestnut Oak	25.1	1968	1
Cherokee	Watauga	Watauga	77	Northern Red Oak	35.6	1902	2
Cherokee	Watauga	Watauga	78	Scarlet Oak	37.6	1917	2
Cherokee	Watauga	Watauga	79	Chestnut Oak	26.2	1967	1
Cherokee	Watauga	Watauga	80	Northern Red Oak	44.5	1940	2
Cherokee	Watauga	Watauga	81	Scarlet Oak	35.6	1914	2
Cherokee	Watauga	Watauga	82	Chestnut Oak	22.6	1966	1
Cherokee	Watauga	Watauga	83	Scarlet Oak	44.2	DEAD	
Cherokee	Watauga	Watauga	84	Chestnut Oak	25.4	1970	2
Cherokee	Watauga	Watauga	85	Scarlet Oak	45.7	1913	2
Cherokee	Watauga	Watauga	86	Chestnut Oak	20.8	1968	2
Cherokee	Watauga	Watauga	87	Scarlet Oak	33.5	1915	1
Cherokee	Watauga	Watauga	88	Chestnut Oak	20.3	1968	2
Cherokee	Watauga	Watauga	89	Scarlet Oak	49.0	1913	2
Cherokee	Watauga	Watauga	90	Chestnut Oak	19.3	1967	1
Cherokee	Watauga	Watauga	91	Scarlet Oak	36.6	1917	2
Cherokee	Watauga	Watauga	92	Chestnut Oak	16.8	1969	2
Cherokee	Watauga	Watauga	93	Scarlet Oak	51.6	1917	2
Cherokee	Watauga	Watauga	94	Chestnut Oak	22.9	1967	1
Cherokee	Watauga	Watauga	95	Scarlet Oak	62.2	1882	2
Cherokee	Watauga	Watauga	96	Chestnut Oak	19.6	1969	2
Cherokee	Watauga	Watauga	97	Chestnut Oak	27.4	1970	2
Cherokee	Watauga	Watauga	98	Chestnut Oak	23.9	1967	2
Cherokee	Watauga	Watauga	99	Chestnut Oak	23.1	1965	2
Cherokee	Watauga	Watauga	100	Chestnut Oak	33.8	1917	2
Cherokee	Watauga	Watauga	101	Chestnut Oak	39.1	1854	2
Cherokee	Watauga	Watauga	102	Chestnut Oak	25.4	1920	2
Cherokee	Watauga	Watauga	103	Chestnut Oak	25.4	1920	2
Cherokee	Watauga	Watauga	104	Chestnut Oak	41.4	1913	2
Cherokee	Watauga	Watauga	105	Chestnut Oak	34.8	1910	1
Cherokee	Watauga	Watauga	106	Chestnut Oak	39.1	1911	2
Cherokee	Watauga	Watauga	107	Chestnut Oak	35.3	1902	2
Cherokee	Watauga	Watauga	108	Chestnut Oak	50.3	1916	2
Cherokee	Watauga	Watauga	109	Chestnut Oak	46.0	1909	2
Cherokee	Watauga	Watauga	110	Chestnut Oak	45.0	1902	2
Cherokee	Watauga	Watauga	111	Chestnut Oak	51.1	1901	2
Pisgah	Bike Trail	Bike Trail	1	Northern Red Oak	97.5	1895	4
Pisgah	Bike Trail	Bike Trail	2	White Oak	48.8	1853	2
Pisgah	Bike Trail	Bike Trail	3	Northern Red Oak	52.3	1862	2
Pisgah	Bike Trail	Bike Trail	4	Northern Red Oak	64.5	1871	2
Pisgah	Bike Trail	Bike Trail	5	Chestnut Oak	50.0	1855	2
Pisgah	Bike Trail	Bike Trail	6	Black Oak	38.1	1866	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Pisgah	Bike Trail	Bike Trail	7	White Oak	50.5	1872	2
Pisgah	Bike Trail	Bike Trail	8	Chestnut Oak	22.4	1901	1
Pisgah	Bike Trail	Bike Trail	9	Black Oak	26.9		
Pisgah	Bike Trail	Bike Trail	10	White Oak	28.2	1884	2
Pisgah	Bike Trail	Bike Trail	11	Black Oak	42.4	1869	2
Pisgah	Bike Trail	Bike Trail	12	White Oak	75.7	1824	2
Pisgah	Bike Trail	Bike Trail	13	Northern Red Oak	43.9	1916	2
Pisgah	Bike Trail	Bike Trail	14	Black Oak	64.5	1914	2
Pisgah	Bike Trail	Bike Trail	15	Northern Red Oak	65.3	1909	2
Pisgah	Bike Trail	Bike Trail	16	White Oak	78.5	1716	2
Pisgah	Bike Trail	Bike Trail	17	White Oak	54.6	1878	2
Pisgah	Bike Trail	Bike Trail	18	Black Oak	46.7	1916	2
Pisgah	Bike Trail	Bike Trail	19	Northern Red Oak	53.8	1914	1
Pisgah	Bike Trail	Bike Trail	20	Northern Red Oak	49.8	1917	2
Pisgah	Bike Trail	Bike Trail	21	Black Oak	43.2	1924	2
Pisgah	Bike Trail	Bike Trail	22	Northern Red Oak	71.6	1907	2
Pisgah	Bike Trail	Bike Trail	23	White Oak	71.6	1855	2
Pisgah	Bike Trail	Bike Trail	24	Chestnut Oak	56.4	1845	2
Pisgah	Bike Trail	Bike Trail	25	Northern Red Oak	83.6	1889	2
Pisgah	Bike Trail	Bike Trail	26	Black Oak	63.0	1845	2
Pisgah	Bike Trail	Bike Trail	27	Black Oak	44.7	1893	2
Pisgah	Bike Trail	Bike Trail	28	White Oak	66.8	1825	2
Pisgah	Bike Trail	Bike Trail	29	Scarlet Oak	64.5	1922	2
Pisgah	Bike Trail	Bike Trail	30	Black Oak	63.0	1811	3
Pisgah	Bike Trail	Bike Trail	31	Scarlet Oak	65.0	1899	2
Pisgah	Bike Trail	Bike Trail	32	Scarlet Oak	42.2	1899	1
Pisgah	Bike Trail	Bike Trail	33	Scarlet Oak	38.9	1901	2
Pisgah	Bike Trail	Bike Trail	34	Northern Red Oak	33.0	1901	1
Pisgah	Bike Trail	Bike Trail	35	Black Oak	29.0	1862	2
Pisgah	Bike Trail	Bike Trail	36	Scarlet Oak	52.3	1915	2
Pisgah	Bike Trail	Bike Trail	37	Chestnut Oak	22.6	1901	2
Pisgah	Bike Trail	Bike Trail	38	Scarlet Oak	47.0	1903	2
Pisgah	Bike Trail	Bike Trail	39	Scarlet Oak	68.6	1913	2
Pisgah	Boyd Branch	Boyd Branch	11	Black Oak	42.2		
Pisgah	Boyd Branch	Boyd Branch	22	White Oak	41.1	1904	2
Pisgah	Boyd Branch	Boyd Branch	33	White Oak	41.9	1860	2
Pisgah	Boyd Branch	Boyd Branch	44	Scarlet Oak	41.7	1910	2
Pisgah	Boyd Branch	Boyd Branch	55	Northern Red Oak	34.0	1894	1
Pisgah	Boyd Branch	Boyd Branch	66	Black Oak	44.2	1894	2
Pisgah	Buell Plot	Buell Plot	1	Scarlet Oak	60.7	1877	2
Pisgah	Buell Plot	Buell Plot	2	White Oak	74.9	1777	3
Pisgah	Buell Plot	Buell Plot	3	Scarlet Oak	47.2	1872	1
Pisgah	Buell Plot	Buell Plot	4	Chestnut Oak	53.6	1859	2
Pisgah	Buell Plot	Buell Plot	5	White Oak	35.1	1934	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Pisgah	Buell Plot	Buell Plot	6	Black Oak	35.8	1934	2
Pisgah	Buell Plot	Buell Plot	7	White Oak	34.3	1938	2
Pisgah	Buell Plot	Buell Plot	8	White Oak	26.4	1941	2
Pisgah	Buell Plot	Buell Plot	9	Black Oak	31.2	1934	2
Pisgah	Buell Plot	Buell Plot	10	White Oak	32.5	1932	1
Pisgah	Buell Plot	Buell Plot	11	Chestnut Oak	34.0	1942	2
Pisgah	Buell Plot	Buell Plot	12	Scarlet Oak	32.0	1942	3
Pisgah	Buell Plot	Buell Plot	13	Scarlet Oak	41.4	1944	2
Pisgah	Buell Plot	Buell Plot	14	Chestnut Oak	22.9	1932	2
Pisgah	Buell Plot	Buell Plot	15	Chestnut Oak	31.5	1932	2
Pisgah	Buell Plot	Buell Plot	16	Northern Red Oak	33.3	1942	2
Pisgah	Buell Plot	Buell Plot	17	Scarlet Oak	31.0	1933	1
Pisgah	Buell Plot	Buell Plot	18	Scarlet Oak	38.9	1941	2
Pisgah	Buell Plot	Buell Plot	19	Chestnut Oak	41.7	1937	2
Pisgah	Buell Plot	Buell Plot	20	Chestnut Oak	34.0	1936	2
Pisgah	Buell Plot	Buell Plot	21	Northern Red Oak	24.9	1933	2
Pisgah	Buell Plot	Buell Plot	22	Chestnut Oak	32.5	1932	2
Pisgah	Buell Plot	Buell Plot	23	Chestnut Oak	24.6	1932	1
Pisgah	Buell Plot	Buell Plot	24	Chestnut Oak	39.6	1937	2
Pisgah	Buell Plot	Buell Plot	25	Scarlet Oak	30.0	1935	2
Pisgah	Buell Plot	Buell Plot	26	Scarlet Oak			
Pisgah	Buell Plot	Buell Plot	27	Northern Red Oak	27.9	1940	2
Pisgah	Buell Plot	Buell Plot	28	Chestnut Oak	30.7	1942	2
Pisgah	Buell Plot	Buell Plot	29	Chestnut Oak	29.0	1932	2
Pisgah	Buell Plot	Buell Plot	30	Chestnut Oak	22.4	1941	2
Pisgah	Buell Plot	Buell Plot	31		26.7		
Pisgah	Buell Plot	Buell Plot	32	Chestnut Oak	22.9	1946	2
Pisgah	Buell Plot	Buell Plot	33	Chestnut Oak	34.5	1933	2
Pisgah	Buell Plot	Buell Plot	34	Chestnut Oak	35.8	1932	2
Pisgah	Buell Plot	Buell Plot	35				
Pisgah	Buell Plot	Buell Plot	36	Chestnut Oak	33.8		
Pisgah	Buell Plot	Buell Plot	37	Chestnut Oak	32.0	1934	2
Pisgah	Buell Plot	Buell Plot	38	Chestnut Oak	34.3	1932	2
Pisgah	Buell Plot	Buell Plot	39	Northern Red Oak	35.8	1939	2
Pisgah	Buell Plot	Buell Plot	40	Northern Red Oak	28.7	1933	2
Pisgah	Buell Plot	Buell Plot	41	Northern Red Oak	31.2	1935	2
Pisgah	Buell Plot	Buell Plot	42	Northern Red Oak	45.5	1942	2
Pisgah	Buell Plot	Buell Plot	43	Black Oak	28.4		
Pisgah	Buell Plot	Buell Plot	44	Black Oak	29.7	1935	2
Pisgah	Buell Plot	Buell Plot	45	Black Oak	40.6	1934	2
Pisgah	Buell Plot	Buell Plot	46	Scarlet Oak	50.5	1891	2
Pisgah	Buell Plot	Buell Plot	47	White Oak	41.9	1886	2
Pisgah	Buell Plot	Buell Plot	48	White Oak	38.9	1890	2
Pisgah	Buell Plot	Buell Plot	49	Chestnut Oak	59.2	1883	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	Forest Service Site Name	Sample Site Name	Tree Number	Species	DBH (cm)	Inside Date	Date Quality
Pisgah	Buell Plot	Buell Plot	50	White Oak	51.1	1912	2
Pisgah	Buell Plot	Buell Plot	51	Chestnut Oak	62.2	1846	2
Pisgah	Buell Plot	Buell Plot	52	Scarlet Oak	87.1	1923	2
Pisgah	Green's Lick	Green's Lick	1	Scarlet Oak	42.4	1913	1
Pisgah	Green's Lick	Green's Lick	2	Northern Red Oak	59.2	1857	2
Pisgah	Green's Lick	Green's Lick	3	Chestnut Oak	68.1	1934	4
Pisgah	Green's Lick	Green's Lick	4	Northern Red Oak	65.8		
Pisgah	Green's Lick	Green's Lick	5	Chestnut Oak	60.2	1861	2
Pisgah	Green's Lick	Green's Lick	6	Northern Red Oak	43.7	1896	2
Pisgah	Green's Lick	Green's Lick	7	White Oak	86.9	1934	4
Pisgah	Green's Lick	Green's Lick	8	Chestnut Oak	49.5	1864	2
Pisgah	Green's Lick	Green's Lick	9	Northern Red Oak	69.6	1883	1
Pisgah	Green's Lick	Green's Lick	10	White Oak	69.9	1775	2
Pisgah	Green's Lick	Green's Lick	11	Chestnut Oak	61.0	1802	3
Pisgah	Green's Lick	Green's Lick	12	Chestnut Oak	62.5	1846	2
Pisgah	Green's Lick	Green's Lick	13	Northern Red Oak	74.9	1941	4
Pisgah	Green's Lick	Green's Lick	14	Chestnut Oak	49.0	1889	2
Pisgah	Green's Lick	Green's Lick	15	White Oak	87.4	1862	4
Pisgah	Green's Lick	Green's Lick	16	Northern Red Oak	65.3	1828	2
Pisgah	Green's Lick	Green's Lick	17	White Oak	56.4	1779	2
Pisgah	Green's Lick	Green's Lick	18	Chestnut Oak	77.5	1739	2
Pisgah	Green's Lick	Green's Lick	19	Northern Red Oak	69.1	1854	3
Pisgah	Green's Lick	Green's Lick	20	Northern Red Oak	57.2	1878	2
Pisgah	Green's Lick	Green's Lick	21	Northern Red Oak	60.7	1838	1
Pisgah	Green's Lick	Green's Lick	22	Northern Red Oak	61.2	1862	2
Pisgah	Green's Lick	Green's Lick	23	Chestnut Oak	46.7	1870	2
Pisgah	Green's Lick	Green's Lick	24	Chestnut Oak	77.5	1700	3
Pisgah	Green's Lick	Green's Lick	25	Northern Red Oak	73.7	1852	2
Pisgah	Green's Lick	Green's Lick	26	Chestnut Oak	55.4	1864	3
Pisgah	Green's Lick	Green's Lick	27	Northern Red Oak	67.3	1903	2
Pisgah	Green's Lick	Green's Lick	28	Chestnut Oak	55.1	1863	2
Pisgah	Green's Lick	Green's Lick	29	White Oak	40.1	1874	2
Pisgah	Green's Lick	Green's Lick	30	Northern Red Oak	70.9	1892	2
Pisgah	Green's Lick	Green's Lick	31	Northern Red Oak	72.1		
Pisgah	Green's Lick	Green's Lick	32	Northern Red Oak	60.5	1895	2
Pisgah	Green's Lick	Green's Lick	33	Northern Red Oak	83.3	1867	4
Pisgah	Green's Lick	Green's Lick	34	Chestnut Oak	33.8	1863	2
Pisgah	Green's Lick	Green's Lick	35	White Oak	78.2	1857	4
Pisgah	Green's Lick	Green's Lick	36	Chestnut Oak	60.5	1869	3
Pisgah	Green's Lick	Green's Lick	37	Northern Red Oak	96.5	1901	4
Pisgah	Green's Lick	Green's Lick	38	White Oak	53.3	1799	4
Pisgah	Green's Lick	Green's Lick	39	Chestnut Oak	41.1	1858	1
Pisgah	Green's Lick	Green's Lick	40	Black Oak	69.9	1873	3
Pisgah	Green's Lick	Green's Lick	41	Scarlet Oak	42.9	1937	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Pisgah	Green's Lick	Green's Lick	42	Northern Red Oak	84.3	1868	2
Pisgah	Green's Lick	Green's Lick	43	White Oak	61.7	1876	2
Pisgah	Green's Lick	Green's Lick	44	Black Oak	58.4	1888	2
Pisgah	Green's Lick	Green's Lick	45	Black Oak	62.2	1796	1
Pisgah	Green's Lick	Green's Lick	46	Northern Red Oak	78.0	1879	3
Pisgah	Green's Lick	Green's Lick	47	Northern Red Oak	43.2	1864	1
Pisgah	Green's Lick	Green's Lick	48	Northern Red Oak	74.4	1889	3
Pisgah	Green's Lick	Green's Lick	49	Black Oak	62.2	1871	2
Pisgah	Green's Lick	Green's Lick	50	Scarlet Oak	45.2		
Pisgah	Green's Lick	Green's Lick	51	White Oak	57.7	1823	2
Pisgah	Green's Lick	Green's Lick	52	Northern Red Oak	51.6	1928	2
Pisgah	Green's Lick	Green's Lick	53	White Oak	34.0		
Pisgah	Green's Lick	Green's Lick	54	White Oak	75.2	1708	2
Pisgah	Green's Lick	Green's Lick	55	Chestnut Oak	30.5	1879	2
Pisgah	Green's Lick	Green's Lick	56	Northern Red Oak	33.0	1889	1
Pisgah	Green's Lick	Green's Lick	57	Chestnut Oak	27.2	1934	2
Pisgah	Green's Lick	Green's Lick	58	Black Oak	72.6	1837	2
Pisgah	Green's Lick	Green's Lick	59	Northern Red Oak	48.3	1881	2
Pisgah	Green's Lick	Green's Lick	60	Northern Red Oak	54.4	1906	2
Pisgah	Green's Lick	Green's Lick	61	White Oak	35.1	1894	2
Pisgah	Green's Lick	Green's Lick	62	White Oak	63.5	1778	2
Pisgah	Green's Lick	Green's Lick	63	Chestnut Oak	55.6	1881	2
Pisgah	Green's Lick	Green's Lick	64	White Oak	31.5	1892	1
Pisgah	Green's Lick	Green's Lick	65	Northern Red Oak	58.4	1912	2
Pisgah	Green's Lick	Green's Lick	66	White Oak	97.0	1898	4
Pisgah	Green's Lick	Green's Lick	67	Chestnut Oak	62.5	1856	4
Pisgah	Green's Lick	Green's Lick	68	Chestnut Oak	79.0	1855	2
Pisgah	Green's Lick	Green's Lick	69	White Oak	51.6	1778	2
Pisgah	Green's Lick	Green's Lick	70	Chestnut Oak	45.7	1892	1
Pisgah	Green's Lick	Green's Lick	71	Black Oak	41.7	1893	1
Pisgah	Green's Lick	Green's Lick	72	Chestnut Oak	83.1	1736	4
Pisgah	Hard Times	Hard Times	1	Chestnut Oak	65.0	1857	2
Pisgah	Hard Times	Hard Times	2	White Oak	54.4	1870	2
Pisgah	Hard Times	Hard Times	3	Northern Red Oak	50.5	1880	2
Pisgah	Hard Times	Hard Times	4	White Oak	43.2	1864	2
Pisgah	Hard Times	Hard Times	5	Northern Red Oak	51.1	1900	2
Pisgah	Hard Times	Hard Times	6	Chestnut Oak	40.1	1874	3
Pisgah	Hard Times	Hard Times	7	Chestnut Oak	35.1	1889	2
Pisgah	Hard Times	Hard Times	8	Chestnut Oak	99.1	1841	3
Pisgah	Hard Times	Hard Times	9	White Oak	66.0	1728	3
Pisgah	Hard Times	Hard Times	10	Northern Red Oak	57.4	1901	2
Pisgah	Hard Times	Hard Times	11	White Oak	73.2	1814	3
Pisgah	Hard Times	Hard Times	12	White Oak	39.6	1870	1
Pisgah	Hard Times	Hard Times	13	Scarlet Oak	50.5	1908	3

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Pisgah	Hard Times	Hard Times	14	Scarlet Oak	32.5	1876	2
Pisgah	Hard Times	Hard Times	15	Chestnut Oak	34.5	1870	1
Pisgah	Hard Times	Hard Times	16	Chestnut Oak	46.0	1874	2
Pisgah	Hard Times	Hard Times	17	White Oak	29.5	1897	2
Pisgah	Hard Times	Hard Times	18	White Oak	62.7	1760	3
Pisgah	Hard Times	Hard Times	19	Chestnut Oak	84.6	1940	4
Pisgah	Hard Times	Hard Times	20	Chestnut Oak	67.3	1851	2
Pisgah	Hard Times	Hard Times	21	White Oak	37.1	1869	2
Pisgah	Hard Times	Hard Times	22	White Oak	71.6	1728	2
Pisgah	Hard Times	Hard Times	23	White Oak	44.5	1877	3
Pisgah	Hard Times	Hard Times	24	Black Oak	39.4	1889	2
Pisgah	Hard Times	Hard Times	25	Scarlet Oak	38.6	1880	2
Pisgah	Hard Times	Hard Times	26	Chestnut Oak	41.4	1896	2
Pisgah	Hard Times	Hard Times	27	Chestnut Oak	82.8	1855	3
Pisgah	Hard Times	Hard Times	28	Chestnut Oak	78.7	1736	3
Pisgah	Hard Times	Hard Times	29	White Oak	74.4	1768	3
Pisgah	Hard Times	Hard Times	30	Chestnut Oak	61.0	1905	4
Pisgah	Hard Times	Hard Times	31	Chestnut Oak	91.9	1890	4
Pisgah	Hard Times	Hard Times	32	White Oak	40.1	1879	2
Pisgah	Hard Times	Hard Times	33	White Oak	33.5	1869	2
Pisgah	Hard Times	Hard Times	34	Chestnut Oak	37.1	1867	1
Pisgah	Hard Times	Hard Times	35	White Oak	78.2	1723	2
Pisgah	Hard Times	Hard Times	36	White Oak	61.0	1726	2
Pisgah	Hard Times	Hard Times	37	White Oak	80.3	1837	2
Pisgah	Hard Times	Hard Times	38	Northern Red Oak	53.3	1929	2
Pisgah	Hard Times	Hard Times	39	Chestnut Oak	98.8	1834	3
Pisgah	Hard Times	Hard Times	40	White Oak	87.6	1740	3
Pisgah	Hard Times	Hard Times	41	Chestnut Oak	51.3	1890	2
Pisgah	Hard Times	Hard Times	42	White Oak	33.3	1904	2
Pisgah	Hard Times	Hard Times	43	White Oak	68.1	1842	4
Pisgah	Hard Times	Hard Times	44	Chestnut Oak	44.2	1882	2
Pisgah	Hard Times	Hard Times	45	Chestnut Oak	51.1	1875	1
Pisgah	Hard Times	Hard Times	46	White Oak	49.3	1877	3
Pisgah	Hard Times	Hard Times	47	Scarlet Oak	52.6	1952	4
Pisgah	Hard Times	Hard Times	48	White Oak	54.1	1882	2
Pisgah	Hard Times	Hard Times	49	Scarlet Oak	67.8	1887	3
Pisgah	Hard Times	Hard Times	50	White Oak	59.7	1715	1
Pisgah	Hard Times	Hard Times	51	White Oak	77.7	1792	2
Pisgah	Hurricane	Hurricane Gap	1	White Oak	13.7	1977	2
Pisgah	Hurricane	Hurricane Gap	2	Chestnut Oak	18.0	1977	2
Pisgah	Hurricane	Hurricane Gap	3	White Oak	20.8	1975	1
Pisgah	Hurricane	Hurricane Gap	4	Chestnut Oak	18.3	1975	1
Pisgah	Hurricane	Hurricane Gap	5	White Oak	12.4	1977	1
Pisgah	Hurricane	Hurricane Gap	6	Chestnut Oak	15.0	1976	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Pisgah	Hurricane	Hurricane Gap	7	Northern Red Oak	17.3	1978	2
Pisgah	Hurricane	Hurricane Gap	8	Northern Red Oak	12.7	1978	1
Pisgah	Hurricane	Hurricane Gap	9	Chestnut Oak	18.8	1978	2
Pisgah	Hurricane	Hurricane Gap	10	Chestnut Oak	10.9	1981	2
Pisgah	Hurricane	Hurricane Gap	11	Northern Red Oak	11.4	1976	2
Pisgah	Hurricane	Hurricane Gap	12	Chestnut Oak	20.3	1980	2
Pisgah	Hurricane	Hurricane Gap	13	Chestnut Oak	16.8	1980	2
Pisgah	Hurricane	Hurricane Gap	14	Chestnut Oak	19.1	1977	2
Pisgah	Hurricane	Hurricane Gap	15	Northern Red Oak	21.8	1976	2
Pisgah	Hurricane	Hurricane Gap	16	Scarlet Oak	20.8		
Pisgah	Hurricane	Hurricane Gap	17	Chestnut Oak	16.0	1977	2
Pisgah	Hurricane	Hurricane Gap	18	Northern Red Oak	13.7	1976	1
Pisgah	Hurricane	Hurricane Gap	19	Chestnut Oak	15.7	1978	2
Pisgah	Hurricane	Hurricane Gap	20	Chestnut Oak	23.6	1976	2
Pisgah	Hurricane	Hurricane Gap	21	Chestnut Oak	18.8	1980	2
Pisgah	Hurricane	Hurricane Gap	22	Northern Red Oak	11.9	1976	1
Pisgah	Hurricane	Hurricane Gap	23	Northern Red Oak	16.5	1976	1
Pisgah	Hurricane	Hurricane Gap	24	Northern Red Oak	16.0	1976	2
Pisgah	Hurricane	Hurricane Gap	25	Chestnut Oak	15.7	1978	2
Pisgah	Hurricane	Hurricane Gap	26	Northern Red Oak	14.5	1976	1
Pisgah	Hurricane	Hurricane Gap	27	Northern Red Oak	17.5	1976	2
Pisgah	Hurricane	Hurricane Gap	28	Chestnut Oak	19.8	1978	2
Pisgah	Hurricane	Hurricane Gap	29	White Oak	43.9	1893	2
Pisgah	Hurricane	Hurricane Gap	30	Chestnut Oak	57.2	1866	2
Pisgah	Hurricane	Hurricane Gap	31	Chestnut Oak	50.8	1888	2
Pisgah	Hurricane	Hurricane Gap	32	Chestnut Oak	31.0		
Pisgah	Hurricane	Hurricane Gap	33	White Oak	53.3	1840	2
Pisgah	Hurricane	Hurricane Gap	34	Northern Red Oak	34.8	1926	1
Pisgah	Hurricane	Hurricane Gap	35	Chestnut Oak	41.1	1894	1
Pisgah	Hurricane	Hurricane Gap	36	Chestnut Oak	31.8	1936	2
Pisgah	Hurricane	Hurricane Gap	37	Northern Red Oak	48.3	1915	2
Pisgah	Hurricane	Hurricane Gap	38	Northern Red Oak	41.7	1895	2
Pisgah	Hurricane	Hurricane Gap	39	Northern Red Oak	37.3	1933	2
Pisgah	Hurricane	Hurricane Gap	40	Northern Red Oak	32.0	1937	2
Pisgah	Hurricane	Hurricane Gap	41	Chestnut Oak	49.8	1938	2
Pisgah	Hurricane	Hurricane Gap	42	Northern Red Oak	62.2	1934	2
Pisgah	Hurricane	Hurricane Gap	43	Northern Red Oak	57.7	1929	3
Pisgah	Hurricane	Hurricane Gap	44	White Oak	74.7	1795	2
Pisgah	Mill Ridge	Mill Ridge	1	Chestnut Oak	17.0	1975	1
Pisgah	Mill Ridge	Mill Ridge	2	Chestnut Oak	20.8	1974	1
Pisgah	Mill Ridge	Mill Ridge	3	Scarlet Oak	16.8	1978	2
Pisgah	Mill Ridge	Mill Ridge	4	Scarlet Oak	14.5	1977	2
Pisgah	Mill Ridge	Mill Ridge	5	Scarlet Oak	20.6	1976	2
Pisgah	Mill Ridge	Mill Ridge	6	Chestnut Oak	18.8	1974	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Pisgah	Mill Ridge	Mill Ridge	7	White Oak	13.5	1977	2
Pisgah	Mill Ridge	Mill Ridge	8	Scarlet Oak	18.0	1974	1
Pisgah	Mill Ridge	Mill Ridge	9	Chestnut Oak	15.5	1974	2
Pisgah	Mill Ridge	Mill Ridge	10	Chestnut Oak	17.3	1973	1
Pisgah	Mill Ridge	Mill Ridge	11	Chestnut Oak	16.5	1974	2
Pisgah	Mill Ridge	Mill Ridge	12	Chestnut Oak	22.6	1973	2
Pisgah	Mill Ridge	Mill Ridge	13	Scarlet Oak	44.2	1918	2
Pisgah	Mill Ridge	Mill Ridge	14	White Oak	36.1	1915	1
Pisgah	Mill Ridge	Mill Ridge	15	Scarlet Oak	47.2	1917	2
Pisgah	Mill Ridge	Mill Ridge	16	Chestnut Oak	33.8	1929	2
Pisgah	Mill Ridge	Mill Ridge	17	White Oak	33.0	1917	2
Pisgah	Mill Ridge	Mill Ridge	18	White Oak	29.7	1919	2
Pisgah	Mill Ridge	Mill Ridge	19	Scarlet Oak	34.3	1923	2
Pisgah	Mill Ridge	Mill Ridge	20	White Oak	51.1	1880	2
Pisgah	Mill Ridge	Mill Ridge	21	Chestnut Oak	44.7	1860	2
Pisgah	Mill Ridge	Mill Ridge	22	Chestnut Oak	63.0	1914	4
Pisgah	Mill Ridge	Mill Ridge	23	Chestnut Oak	37.8	1918	1
Pisgah	Mill Ridge	Mill Ridge	24	White Oak	18.0	1975	2
Pisgah	Mill Ridge	Mill Ridge	25	Scarlet Oak	27.2	1974	1
Pisgah	Mill Ridge	Mill Ridge	26	White Oak	28.7	1974	2
Pisgah	Mill Ridge	Mill Ridge	27	Scarlet Oak	23.4	1975	2
Pisgah	Mill Ridge	Mill Ridge	28	White Oak	16.8	1975	1
Pisgah	Mill Ridge	Mill Ridge	29	White Oak	23.6	1967	2
Pisgah	Mill Ridge	Mill Ridge	30	White Oak	16.8	1962	1
Pisgah	Mill Ridge	Mill Ridge	31	White Oak	17.0	1934	2
Pisgah	Mill Ridge	Mill Ridge	32	White Oak	20.3	1975	1
Pisgah	Mill Ridge	Mill Ridge	33	Scarlet Oak	27.4	1975	2
Pisgah	Mill Ridge	Mill Ridge	34	Scarlet Oak	20.3	1979	2
Pisgah	Mill Ridge	Mill Ridge	35	Scarlet Oak	18.8	1974	1
Pisgah	Old Gate	Old Gate	1	Scarlet Oak	51.8	1904	2
Pisgah	Old Gate	Old Gate	2	White Oak	53.8	1853	3
Pisgah	Old Gate	Old Gate	3	White Oak	50.8	1898	4
Pisgah	Old Gate	Old Gate	4	Scarlet Oak	36.3	1927	2
Pisgah	Old Gate	Old Gate	5	Chestnut Oak	47.2	1889	2
Pisgah	Old Gate	Old Gate	6	Scarlet Oak	65.8	1908	2
Pisgah	Old Gate	Old Gate	7	Chestnut Oak	46.0	1911	2
Pisgah	Old Gate	Old Gate	8	Chestnut Oak	43.2	1915	3
Pisgah	Old Gate	Old Gate	9	Scarlet Oak	55.4		
Pisgah	Old Gate	Old Gate	10	Chestnut Oak	47.8	1902	1
Pisgah	Old Gate	Old Gate	11	White Oak	51.8	1881	2
Pisgah	Old Gate	Old Gate	12	Scarlet Oak	50.5	1864	2
Pisgah	Old Gate	Old Gate	13	Chestnut Oak	37.1	1893	2
Pisgah	Old Gate	Old Gate	14	Scarlet Oak	49.5	1932	4
Pisgah	Old Gate	Old Gate	15	White Oak	42.2	1863	1

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	Forest Service Site Name	Sample Site Name	Tree Number	Species	DBH (cm)	Inside Date	Date Quality
Pisgah	Old Gate	Old Gate	16	Scarlet Oak	48.5	1926	4
Pisgah	Old Gate	Old Gate	17	Chestnut Oak	54.4	1892	1
Pisgah	Old Gate	Old Gate	18	Chestnut Oak	30.7	1893	1
Pisgah	Old Gate	Old Gate	19	Chestnut Oak	27.4	1892	2
Pisgah	Old Gate	Old Gate	20	Scarlet Oak	56.9	1905	2
Pisgah	Old Gate	Old Gate	21	Scarlet Oak	39.9	1904	3
Pisgah	Old Gate	Old Gate	22	Chestnut Oak	39.9	1908	2
Pisgah	Old Gate	Old Gate	23	Scarlet Oak	52.6	1912	3
Pisgah	Old Gate	Old Gate	24	Scarlet Oak	69.3	1918	3
Pisgah	Old Gate	Old Gate	25	Scarlet Oak	64.5	1893	2
Pisgah	Old Gate	Old Gate	26	Scarlet Oak	32.5	1896	1
Pisgah	Old Gate	Old Gate	27	Scarlet Oak	54.9		
Pisgah	Old Gate	Old Gate	28	Scarlet Oak	52.3		
Pisgah	Old Gate	Old Gate	29	Scarlet Oak	45.2		
Pisgah	Old Gate	Old Gate	30	Scarlet Oak	26.2		
Pisgah	Old Gate	Old Gate	31	Scarlet Oak	43.9	1894	2
Pisgah	Old Gate	Old Gate	32	Scarlet Oak	40.6	1918	2
Pisgah	Rice Pinnacle	Rice Pinnacle	1	White Oak	15.0	1967	1
Pisgah	Rice Pinnacle	Rice Pinnacle	2	White Oak	13.7	1971	2
Pisgah	Rice Pinnacle	Rice Pinnacle	3	Scarlet Oak	19.1	1969	2
Pisgah	Rice Pinnacle	Rice Pinnacle	4	White Oak	16.0	1968	2
Pisgah	Rice Pinnacle	Rice Pinnacle	5	White Oak	19.3	1967	1
Pisgah	Rice Pinnacle	Rice Pinnacle	6	White Oak	14.0	1968	2
Pisgah	Rice Pinnacle	Rice Pinnacle	7	White Oak	10.2	1967	1
Pisgah	Rice Pinnacle	Rice Pinnacle	8	White Oak	16.8	1968	2
Pisgah	Rice Pinnacle	Rice Pinnacle	9	White Oak	14.5	1967	1
Pisgah	Rice Pinnacle	Rice Pinnacle	10	White Oak	15.0	1968	2
Pisgah	Rice Pinnacle	Rice Pinnacle	11	White Oak	13.0	1968	1
Pisgah	Rice Pinnacle	Rice Pinnacle	12	White Oak	14.7	1958	2
Pisgah	Rice Pinnacle	Rice Pinnacle	13	White Oak	15.2	1968	1
Pisgah	Rice Pinnacle	Rice Pinnacle	14	White Oak	13.0	1968	1
Pisgah	Rice Pinnacle	Rice Pinnacle	15	White Oak	16.0	1969	2
Pisgah	Rice Pinnacle	Rice Pinnacle	16	Scarlet Oak	20.1	1969	2
Pisgah	Rice Pinnacle	Rice Pinnacle	17	Scarlet Oak	18.0	1968	2
Pisgah	Rice Pinnacle	Rice Pinnacle	18	Scarlet Oak	22.1	1968	1
Pisgah	Rice Pinnacle	Rice Pinnacle	19	White Oak	22.6	1968	1
Pisgah	Rice Pinnacle	Rice Pinnacle	20	White Oak	14.5	1968	2
Pisgah	Rice Pinnacle	Rice Pinnacle	21	White Oak	23.1	1967	1
Pisgah	Rice Pinnacle	Rice Pinnacle	22	Scarlet Oak	14.2	1968	2
Pisgah	Rice Pinnacle	Rice Pinnacle	23	White Oak	19.8	1967	1
Pisgah	Rice Pinnacle	Rice Pinnacle	24	Black Oak	13.5	1970	2
Pisgah	Rice Pinnacle	Rice Pinnacle	25	White Oak	24.6	1968	1
Pisgah	Rice Pinnacle	Rice Pinnacle	26	Scarlet Oak	16.3	1968	2
Pisgah	Rice Pinnacle	Rice Pinnacle	27	Scarlet Oak	15.0	1971	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	Forest Service Site Name	Sample Site Name	Tree Number	Species	DBH (cm)	Inside Date	Date Quality
Pisgah	Rice Pinnacle	Rice Pinnacle	28	Scarlet Oak	10.2	1969	2
Pisgah	Rice Pinnacle	Rice Pinnacle	29	Scarlet Oak	14.5	1968	2
Pisgah	Rice Pinnacle	Rice Pinnacle	30	Scarlet Oak	14.7	1968	2
Pisgah	Rice Pinnacle	Rice Pinnacle	31	Scarlet Oak	13.0	1970	2
Pisgah	Rice Pinnacle	Rice Pinnacle	32	Scarlet Oak	9.1	1968	1
Pisgah	Rice Pinnacle	Rice Pinnacle	33	Scarlet Oak	10.9	1973	2
Pisgah	Rice Pinnacle	Rice Pinnacle	34	Scarlet Oak	9.1	1969	2
Pisgah	Rice Pinnacle	Rice Pinnacle	35	Scarlet Oak	13.0	1968	2
Pisgah	Rice Pinnacle	Rice Pinnacle	36	Scarlet Oak	16.5	1969	2
Pisgah	Rice Pinnacle	Rice Pinnacle	37	Scarlet Oak	18.5	1957	1
Pisgah	Rice Pinnacle	Rice Pinnacle	38	Scarlet Oak	12.2	1976	2
Pisgah	Rice Pinnacle	Rice Pinnacle	39	Scarlet Oak	19.6	1968	1
Pisgah	Rice Pinnacle	Rice Pinnacle	40	Scarlet Oak	14.0		
Pisgah	South Ridge	South Ridge	1	Northern Red Oak	65.8	1975	2
Pisgah	South Ridge	South Ridge	2	Northern Red Oak	70.4	1870	2
Pisgah	South Ridge	South Ridge	3	Northern Red Oak	98.6	1914	4
Pisgah	South Ridge	South Ridge	4	Northern Red Oak	65.8	1859	1
Pisgah	South Ridge	South Ridge	5	Northern Red Oak	80.5	1870	3
Pisgah	South Ridge	South Ridge	6	Northern Red Oak	89.4	1960	4
Pisgah	South Ridge	South Ridge	7	Chestnut Oak	64.3	1934	3
Pisgah	South Ridge	South Ridge	8	Chestnut Oak	51.6	1868	2
Pisgah	South Ridge	South Ridge	9	Black Oak	58.2	1867	3
Pisgah	South Ridge	South Ridge	10	Northern Red Oak	66.5	1921	2
Pisgah	South Ridge	South Ridge	11	Northern Red Oak	51.6	1861	2
Pisgah	South Ridge	South Ridge	12	White Oak	34.5	1915	2
Pisgah	South Ridge	South Ridge	13	Chestnut Oak	35.8	1896	1
Pisgah	South Ridge	South Ridge	14	Northern Red Oak	48.0	1918	2
Pisgah	South Ridge	South Ridge	15	Northern Red Oak	34.8		
Pisgah	South Ridge	South Ridge	16	Northern Red Oak	25.9	1908	2
Pisgah	South Ridge	South Ridge	17	Chestnut Oak	33.8	1903	1
Pisgah	South Ridge	South Ridge	18	Chestnut Oak	35.3		
Pisgah	South Ridge	South Ridge	19	Chestnut Oak	28.2	1930	2
Pisgah	South Ridge	South Ridge	20	Scarlet Oak	35.6	1916	2
Pisgah	South Ridge	South Ridge	21	Scarlet Oak	31.8	1898	2
Pisgah	South Ridge	South Ridge	22	White Oak	31.5	1871	2
Pisgah	South Ridge	South Ridge	23	Chestnut Oak	33.0	1905	2
Pisgah	South Ridge	South Ridge	24	White Oak	24.4	1875	2
Pisgah	South Ridge	South Ridge	25	White Oak	36.1	1870	2
Pisgah	South Ridge	South Ridge	26	Northern Red Oak	32.0	1882	2
Pisgah	South Ridge	South Ridge	27	Black Oak	36.8	1894	2
Pisgah	South Ridge	South Ridge	28	Scarlet Oak	27.7	1935	2
Pisgah	South Ridge	South Ridge	29	White Oak	26.4	1913	2
Pisgah	South Ridge	South Ridge	30	Scarlet Oak	32.5	1919	2
Pisgah	South Ridge	South Ridge	31	White Oak	29.0	1911	2

Table A-1 (continued). Inside dates of the USFS mast trees and the date quality of those measurements.

National Forest	*Forest Service Site Name*	*Sample Site Name*	*Tree Number*	*Species*	*DBH (cm)*	*Inside Date*	*Date Quality*
Pisgah	South Ridge	South Ridge	32	Scarlet Oak	34.3	1905	2
Pisgah	South Ridge	South Ridge	33	Scarlet Oak	27.9	1899	2
Pisgah	South Ridge	South Ridge	34	Chestnut Oak	23.1	1895	2
Pisgah	South Ridge	South Ridge	35	Chestnut Oak	29.5	1897	2
Pisgah	South Ridge	South Ridge	36	Chestnut Oak	20.3	1915	2
Pisgah	South Ridge	South Ridge	37		30.5		
Pisgah	South Ridge	South Ridge	38	Chestnut Oak	33.5	1918	2
Pisgah	South Ridge	South Ridge	39	White Oak	23.1	1898	2
Pisgah	South Ridge	South Ridge	40	Scarlet Oak	22.6	1925	2
Pisgah	South Ridge	South Ridge	41	Chestnut Oak	32.3	1876	2
Pisgah	South Ridge	South Ridge	42	Scarlet Oak	34.0	1884	2
Pisgah	South Ridge	South Ridge	43	Chestnut Oak	22.4	1898	2
Pisgah	South Ridge	South Ridge	44	Chestnut Oak	37.3	1873	1
Pisgah	South Ridge	South Ridge	45	Chestnut Oak	23.4	1917	2
Pisgah	South Ridge	South Ridge	46	Northern Red Oak	20.8	1962	3
Pisgah	South Ridge	South Ridge	47	Chestnut Oak	38.1	1872	2
Pisgah	South Ridge	South Ridge	48	Scarlet Oak	35.1		
Pisgah	South Ridge	South Ridge	49	Chestnut Oak	30.0	1874	2
Pisgah	South Ridge	South Ridge	50				
Pisgah	South Ridge	South Ridge	51	Northern Red Oak	36.3		
Pisgah	South Ridge	South Ridge	52	Northern Red Oak	34.0	1903	2
Pisgah	South Ridge	South Ridge	53	Chestnut Oak	26.2	1949	3
Pisgah	South Ridge	South Ridge	54	Chestnut Oak	32.8	1875	2
Pisgah	South Ridge	South Ridge	55	Chestnut Oak	35.3		
Pisgah	South Ridge	South Ridge	56	Chestnut Oak	38.9		

Appendix B: The regression results from the tree-level mast analysis

This appendix contains all of the regression results at the individual tree level between the tree-ring index and USFS mast data for each tree. N is the number of years of data for each tree. Most trees have six years of data for 1993 through 1998. The trees with n less than six are usually missing mast data for one or more years. The sign shows whether the result was a positive or negative correlation with mast. Significance reported at the 0.1 and 0.05 levels is indicated by asterisks.

Table B-1. Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Chattahoochee Cohutta Scarlet Oak							
	coh 18	0.024	0.803	5	+		
	coh 19	0.006	0.886	6	+		
	coh 22	0.067	0.741	4	-		
	coh 23	0.103	0.679	4	-		
	coh 27	0.566	0.085	6	-	*	
	coh 28	0.137	0.470	6	+		
	coh 29	0.063	0.631	6	-		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Chattahoochee Cohutta Chestnut Oak							
	coh 02	0.448	0.146	6	+		
	coh 05	0.049	0.674	6	-		
	coh 06	0.007	0.871	6	+		
	coh 07	0.119	0.119	6	+		
	coh 10	0.466	0.135	6	+		
	coh 15	0.074	0.602	6	+		
	coh 16	0.277	0.277	6	+		
	coh 24	0.344	0.221	6	+		
	coh 25	0.327	0.235	6	+		
	coh 26	0.582	0.078	6	+	*	
	coh 30	0.128	0.487	6	+		
Chattahoochee Cohutta White Oak							
	coh 01	0.723	0.032	6	-	*	*
	coh 03	0.158	0.435	6	+		
	coh 11	0.060	0.641	6	-		
	coh 13	0.060	0.640	6	-		
	coh 14	0.006	0.879	6	+		
	coh 17	0.201	0.373	6	-		
Chattahoochee Tallulah Northern red Oak							
Not enough good mast data at the individual tree level.							
Chattahoochee Tallulah Chestnut Oak							
Not enough good mast data at the individual tree level.							
Chattahoochee Tallulah White Oak							
Not enough good mast data at the individual tree level.							
Chattahoochee Work Center White Oak							
	wrc 02	0.028	0.752	6	+		
	wrc 04	0.175	0.408	6	+		
	wrc 05	0.158	0.435	6	-		
	wrc 06	0.185	0.395	6	+		
	wrc 11	0.001	0.944	6	-		
	wrc 12	0.147	0.453	6	+		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Cherokee Burnett Gap Black Oak							
	bug 51	0.059	0.643	6	+		
	bug 57	0.443	0.149	6	-		
	bug 58	0.002	0.927	6	+		
	bug 59	0.115	0.510	6	+		
	bug 61	0.036	0.720	6	-		
	bug 65	0.079	0.589	6	+		
Cherokee Burnett Gap Northern Red Oak							
	bug 25	0.022	0.779	6	+		
	bug 26	0.035	0.723	6	-		
	bug 68	0.170	0.417	6	+		
	bug 69	0.070	0.612	6	+		
	bug 70	0.186	0.393	6	-		
Cherokee Burnett Gap Scarlet Oak							
	bug 36	0.013	0.828	6	-		
	bug 37	0.120	0.502	6	-		
	bug 38	0.146	0.454	6	-		
	bug 39	0.161	0.431	6	-		
	bug 40	0.134	0.475	6	-		
	bug 41	0.303	0.258	6	-		
	bug 42	0.003	0.918	6	-		
	bug 44	0.365	0.204	6	-		
	bug 60	0.167	0.421	6	-		
	bug 62	0.572	0.082	6	-	*	
	bug 66	0.170	0.417	6	-		
Cherokee Burnett Gap Chestnut Oak							
	bug 43	0.014	0.821	6	-		
	bug 47	0.205	0.367	6	-		
	bug 48	0.092	0.558	6	+		
	bug 49	0.002	0.928	6	-		
	bug 50	0.405	0.175	6	+		
	bug 52	0.117	0.507	6	+		
	bug 53	0.127	0.487	6	+		
	bug 71	0.453	0.143	6	+		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	*p < 0.1*	*p < 0.05*
Cherokee Burnett Gap White Oak							
	bug 27	0.213	0.357	6	+		
	bug 29	0.023	0.777	6	-		
	bug 45	0.287	0.273	6	+		
	bug 54	0.003	0.920	6	+		
	bug 55	0.039	0.708	6	+		
	bug 56	0.012	0.834	6	-		
	bug 63	0.031	0.739	6	-		
	bug 64	0.013	0.832	6	-		
	bug 67	0.055	0.656	6	-		
Cherokee Hiawassee B White Oak							
	hib 34	0.287	0.273	6	+		
	hib 35	0.117	0.508	6	+		
	hib 36	0.084	0.576	6	+		
	hib 37	0.094	0.555	6	+		
	hib 38	0.049	0.675	6	+		
	hib 39	0.001	0.957	6	-		
	hib 40	0.336	0.228	6	-		
	hib 41	0.005	0.892	6	+		
	hib 42	0.006	0.882	6	-		
	hib 43	0.018	0.801	6	-		
Cherokee Hiawassee C Black Oak							
	hic 03	0.799	0.016	6	-	*	*
	hic 04	0.239	0.325	6	-		
	hic 06	0.004	0.907	6	-		
	hic 11	0.208	0.363	6	-		
	hic 14	0.001	0.964	6			
	hic 21	0.584	0.132	5	-		
	hic 28	0.105	0.532	6	-		
	hic 29	0.014	0.822	6	-		
	hic 32	0.000	0.991	6			

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Cherokee Hiawassee C Scarlet Oak							
	hic 01	0.800	0.016	6	-	*	*
	hic 02	0.594	0.073	6	-	*	
	hic 15	0.085	0.575	6	-		
	hic 18	0.303	0.258	6	-		
	hic 19	0.059	0.644	6	-		
	hic 20	0.093	0.556	6	-		
	hic 22	0.155	0.439	6	-		
	hic 23	0.037	0.715	6	-		
	hic 27	0.125	0.493	6	-		
	hic 31	0.880	0.006	6	-	*	*
Cherokee Hiawassee C Chestnut Oak							
	hic 07	0.505	0.113	6	+		
	hic 08	0.400	0.178	6	+		
	hic 09	0.166	0.422	6	+		
	hic 10	0.638	0.057	6	+	*	
	hic 12	0.174	0.410	6	+		
	hic 13	0.200	0.374	6	+		
	hic 17	0.130	0.483	6	+		
	hic 24	0.083	0.581	6	+		
	hic 25	0.878	0.006	6	+	*	*
	hic 33	0.663	0.049	6	+	*	*
Cherokee Jackson Farm Black Oak							
	jkf 03	0.002	0.947	6	+		
	jkf 04	0.012	0.838	6	+		
	jkf 12	0.086	0.572	6	+		
	jkf 14	0.171	0.416	6	+		
	jkf 15	0.004	0.911	6	+		
	jkf 16	0.055	0.654	6	-		
	jkf 17	0.097	0.548	6	-		
	jkf 21	0.052	0.665	6	-		
	jkf 40	0.130	0.483	6	-		
	jkf 41	0.041	0.700	6	+		
	jkf 51	0.211	0.359	6	-		
	jkf 59	0.000	0.993	6			
	jkf 61	0.224	0.343	6	+		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Cherokee Jackson Farm Northern Red Oak							
	jkf 08	0.088	0.628	5	-		
	jkf 11	0.231	0.335	6	-		
	jkf 13	0.003	0.922	6	-		
	jkf 29	0.090	0.563	6	-		
	jkf 46	0.222	0.345	6	-		
	jkf 47	0.002	0.932	6	+		
	jkf 52	0.308	0.253	6	-		
	jkf 56	0.108	0.525	6	+		
	jkf 57	0.342	0.223	6	+		
	jkf 62	0.816	0.014	6	-	*	*
Cherokee Jackson Farm Scarlet Oak							
	jkf 05	0.145	0.457	6	+		
	jkf 20	0.546	0.093	6	-	*	
	jkf 22	0.630	0.059	6	+	*	
	jkf 35	0.064	0.628	6	+		
	jkf 36	0.055	0.704	6	+		
	jkf 37	0.030	0.743	6	+		
	jkf 38	0.067	0.621	6	+		
	jkf 39	0.000	0.992	6			
	jkf 42	0.001	0.956	5	-		
	jkf 44	0.536	0.098	6	+	*	
	jkf 55	0.515	0.108	6	-		
	jkf 63	0.324	0.238	6	-		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Cherokee Jackson Farm Chestnut Oak							
	jkf 19	0.422	0.162	6	-		
	jkf 23	0.266	0.295	6	-		
	jkf 24	0.288	0.273	6	+		
	jkf 25	0.474	0.131	6	+		
	jkf 26	0.216	0.353	6	+		
	jkf 28	0.051	0.668	6	-		
	jkf 30	0.097	0.547	6	+		
	jkf 31	0.061	0.638	6	-		
	jkf 32	0.270	0.291	6	+		
	jkf 33	0.080	0.645	5	-		
	jkf 34	0.059	0.643	6	+		
	jkf 53	0.236	0.329	6	+		
	jkf 54	0.063	0.748	4	-		
Cherokee Jackson Farm White Oak							
	jkf 02	0.039	0.708	6	-		
	jkf 06	0.023	0.808	5	+		
	jkf 07	0.002	0.940	5	+		
	jkf 09	0.001	0.956	6	+		
	jkf 10	0.304	0.257	6	+		
	jkf 27	0.036	0.720	6	-		
	jkf 43	0.038	0.710	6	+		
	jkf 45	0.037	0.716	6	+		
	jkf 48	0.098	0.547	6	-		
	jkf 49	0.051	0.666	6	+		
	jkf 60	0.132	0.479	6	+		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	*p < 0.1*	*p < 0.05*
Cherokee Tellico Black Oak							
	tel 01	0.556	0.089	6	-	*	
	tel 19	0.372	0.199	6	-		
	tel 31	0.464	0.136	6	-		
	tel 22	0.087	0.087	6	-	*	
	tel 27	0.202	0.372	6	-		
	tel 28	0.396	0.181	6	-		
	tel 29	0.065	0.626	6	-		
	tel 30	0.475	0.130	6	-		
	tel 32	0.375	0.196	6	-		
	tel 34	0.627	0.061	6	-	*	
	tel 37	0.064	0.630	6	-		
	tel 41	0.363	0.206	6	-		
	tel 43	0.429	0.158	6	-		
	tel 45	0.102	0.537	6	-		
	tel 46	0.058	0.645	6	-		
	tel 50	0.095	0.552	6	-		
	tel 51	0.565	0.085	6	-	*	
	tel 56	0.201	0.373	6	-		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Cherokee Tellico Northern Red Oak							
	tel 02	0.045	0.687	6	-		
	tel 04	0.154	0.441	6	-		
	tel 05	0.003	0.917	6	+		
	tel 07	0.184	0.396	6	-		
	tel 08	0.191	0.386	6	-		
	tel 09	0.305	0.256	6	+		
	tel 10	0.057	0.648	6	-		
	tel 11	0.572	0.139	5	-		
	tel 12	0.468	0.134	6	-		
	tel 13	0.035	0.724	6	-		
	tel 18	0.034	0.727	6	+		
	tel 20	0.034	0.727	6	+		
	tel 31	0.039	0.706	6	-		
	tel 36	0.159	0.434	6	-		
	tel 60	0.035	0.722	6	-		
	tel 61	0.023	0.772	6	-		
	tel 62	0.434	0.155	6	+		
	tel 63	0.511	0.110	6	-		
Cherokee Tellico Scarlet Oak							
	tel 55	0.134	0.476	6	-		
	tel 57	0.002	0.935	6	-		
	tel 58	0.239	0.325	6	-		
	tel 59	0.060	0.640	6	-		
	tel 65	0.508	0.112	6	-		
	tel 67	0.608	0.068	6	-	*	
	tel 68	0.003	0.915	6	-		
	tel 70	0.369	0.201	6	-		
	tel 71	0.755	0.025	6	-	*	*
	tel 72	0.217	0.351	6	+		
	tel 73	0.006	0.884	6	-		
	tel 75	0.211	0.359	6	-		
	tel 76	0.459	0.139	6	-		
	tel 78	0.184	0.396	6	-		
	tel 79	0.696	0.039	6	-	*	*

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Cherokee Tellico Chestnut Oak							
	tel 03	0.036	0.719	6	-		
	tel 06	0.001	0.957	6			
	tel 14	0.050	0.669	6	-		
	tel 15	0.055	0.654	6	-		
	tel 16	0.213	0.356	6	-		
	tel 17	0.004	0.901	6			
	tel 23	0.003	0.915	6	+		
	tel 24	0.032	0.735	6	-		
	tel 25	0.169	0.418	6	-		
	tel 26	0.015	0.815	6	-		
	tel 33	0.118	0.505	6	+		
	tel 38	0.393	0.183	6	+		
	tel 39	0.042	0.699	6	+		
	tel 40	0.106	0.528	6	+		
	tel 52	0.272	0.288	6	-		
	tel 53	0.127	0.488	6	+		
	tel 54	0.003	0.922	6	+		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Cherokee Tellico White Oak							
	tel 35	0.393	0.183	6	+		
	tel 42	0.393	0.183	6	-		
	tel 47	0.012	0.835	6	+		
	tel 48	0.012	0.835	6			
	tel 49	0.232	0.334	6			
	tel 74	0.001	0.957	6	-		
	tel 77	0.010	0.853	6	+		
	tel 80	0.219	0.349	6	+		
	tel 81	0.153	0.444	6	+		
	tel 82	0.155	0.441	6	+		
	tel 83	0.105	0.532	6	+		
	tel 84	0.397	0.180	6	+		
	tel 85	0.366	0.204	6	+		
	tel 86	0.171	0.415	6	+		
	tel 87	0.059	0.644	6	+		
	tel 88	0.180	0.402	6	+		
	tel 89	0.346	0.219	6	+		
	tel 90	0.100	0.542	6	+		
Pisgah Buell Plot Northern Red Oak							
	bp 16	0.077	0.594	6	-		
	bp 21	0.016	0.812	6	-		
	bp 27	0.013	0.829	6	-		
	bp 39	0.050	0.672	6	+		
	bp 40	0.085	0.575	6	+		
	bp 41	0.000	0.993	6			
	bp 42	0.185	0.185	6	-		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	*p < 0.1*	*p < 0.05*
Pisgah Buell Plot Scarlet Oak							
	bp 01	0.058	0.645	6	-		
	bp 03	0.341	0.341	6	-		
	bp 12	0.643	0.055	6	-	*	
	bp 13	0.635	0.058	6	-	*	
	bp 17	0.003	0.921	6	-		
	bp 18	0.460	0.139	6	-		
	bp 25	0.040	0.705	6	-		
	bp 46	0.099	0.544	6	-		
	bp 52	0.125	0.492	6	-		
Pisgah Buell Plot Chestnut Oak							
	bp 04	0.011	0.845	6	+		
	bp 11	0.172	0.413	6	-		
	bp 15	0.033	0.730	6	-		
	bp 19	0.069	0.616	6	-		
	bp 22	0.006	0.883	6	+		
	bp 23	0.004	0.904	6	+		
	bp 24	0.005	0.893	6	-		
	bp 28	0.305	0.256	6	+		
	bp 29	0.526	0.103	6	+		
	bp 30	0.372	0.198	6	+		
	bp 32	0.053	0.662	6	+		
	bp 37	0.086	0.572	6	+		
	bp 49	0.000	0.972	5			
	bp 51	0.015	0.817	6	+		
Pisgah Buell Plot White Oak							
	bp 02	0.294	0.266	6	+		
	bp 05	0.140	0.466	6	+		
	bp 07	0.169	0.419	6	-		
	bp 08	0.107	0.528	6	+		
	bp 10	0.340	0.224	6	+		
	bp 47	0.000	0.993	6			
	bp 50	0.283	0.277	6	+		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Pisgah Bike Trail Black Oak							
	bt 06	0.183	0.472	5	-		
	bt 11	0.062	0.686	5	-		
	bt 14	0.134	0.544	5	-		
	bt 18	0.420	0.237	5	+		
	bt 21	0.526	0.166	5	+		
	bt 26	0.133	0.546	5	-		
	bt 27	0.120	0.568	5	+		
	bt 30	0.003	0.929	5	+		
	bt 35	0.041	0.745	5	-		
Pisgah Bike Trail Northern Red Oak							
	bt 01	0.183	0.472	5	-		
	bt 03	0.526	0.165	5	-		
	bt 04	0.148	0.522	5	-		
	bt 13	0.162	0.502	5	-		
	bt 15	0.317	0.323	5	+		
	bt 19	0.631	0.108	5	+		
	bt 20	0.003	0.928	5	+		
	bt 22	0.555	0.148	5	+		
	bt 25	0.045	0.733	5	-		
	bt 34	0.733	0.064	5	-	*	
Pisgah Bike Trail Scarlet Oak							
	bt 29	0.030	0.781	5	-		
	bt 31	0.174	0.485	5	+		
	bt 32	0.318	0.322	5	+		
	bt 33	0.271	0.368	5	-		
	bt 36	0.142	0.532	5	-		
	bt 38	0.332	0.310	5	+		
	bt 39	0.138	0.539	5	+		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Pisgah Bike Trail White Oak							
	bt 02	0.063	0.684	5	+		
	bt 07	0.004	0.915	5	+		
	bt 10	0.168	0.493	5	-		
	bt 12	0.208	0.440	5	+		
	bt 16	0.435	0.226	5	-		
	bt 17	0.341	0.301	5	+		
	bt 23	0.200	0.451	5	+		
	bt 28	0.249	0.392	5	-		
Pisgah Green's Lick Black Oak							
	gl 40	0.740	0.061	5	-	*	
	gl 44	0.205	0.444	5	+		
	gl 45	0.127	0.556	5	-		
	gl 49	0.047	0.726	5	-		
	gl 58	0.144	0.528	5	+		
	gl 71	0.250	0.391	5	+		
Pisgah Green's Lick Northern Red Oak							
	gl 02	0.426	0.233	5	-		
	gl 06	0.560	0.146	5	+		
	gl 09	0.896	0.015	5	-	*	*
	gl 13	0.927	0.009	5	-	*	*
	gl 16	0.405	0.249	5	-		
	gl 19	0.022	0.810	5	-		
	gl 20	0.012	0.861	5	+		
	gl 21	0.140	0.535	5	+		
	gl 22	0.494	0.186	5	-		
	gl 25	0.392	0.259	5	-		
	gl 27	0.872	0.020	5	-	*	*
	gl 30	0.299	0.340	5	-		
	gl 32	0.044	0.736	5	+		
	gl 33	0.891	0.016	5	-	*	*
	gl 37	0.022	0.811	5	+		
	gl 42	0.717	0.070	5	-	*	
	gl 46	0.552	0.150	5	-		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
	gl 47	0.291	0.348	5	-		
	gl 48	0.456	0.211	5	-		
	gl 52	0.221	0.425	5	+		
	gl 56	0.067	0.675	5	-		
	gl 59	0.056	0.702	5	-		
	gl 60	0.029	0.785	5	-		
	gl 65	0.433	0.227	5	-		
Pisgah Green's Lick Chestnut Oak							
	gl 03	0.028	0.788	5	+		
	gl 05	0.353	0.291	5	-		
	gl 08	0.022	0.812	5	-		
	gl 11	0.149	0.521	5	-		
	gl 12	0.010	0.872	5	+		
	gl 14	0.002	0.948	5	+		
	gl 18	0.011	0.866	5	-		
	gl 24	0.218	0.428	5	-		
	gl 26	0.021	0.817	5	-		
	gl 36	0.006	0.905	5	+		
	gl 39	0.365	0.281	5	+		
	gl 55	0.218	0.428	5	+		
	gl 57	0.560	0.146	5	-		
	gl 63	0.346	0.297	5	+		
	gl 67	0.096	0.612	5	-		
	gl 68	0.773	0.049	5	+		
	gl 72	0.046	0.786	4	-		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Pisgah Green's Lick White Oak							
	gl 07	0.053	0.709	5	-		
	gl 10	0.004	0.917	5	-		
	gl 15	0.214	0.433	5	+		
	gl 17	0.006	0.900	5	-		
	gl 29	0.011	0.869	5	-		
	gl 35	0.023	0.806	5	-		
	gl 38	0.000	0.996	5	-		
	gl 43	0.003	0.932	5	-		
	gl 51	0.007	0.897	5	-		
	gl 54	0.007	0.893	5	+		
	gl 61	0.074	0.658	5	-		
	gl 62	0.243	0.399	5	-		
	gl 64	0.001	0.955	5	+		
	gl 66	0.475	0.198	5	-		
	gl 69	0.262	0.378	5	+		
Pisgah Hurricane Gap Northern Red Oak							
	hg 07	0.486	0.190	5	+		
	hg 08	0.117	0.572	5	-		
	hg 15	0.436	0.225	5	-		
	hg 27	0.392	0.259	5	-		
	hg 34	0.349	0.294	5	-		
	hg 37	0.346	0.297	5	+		
	hg 38	0.162	0.501	5	+		
	hg 39	0.433	0.227	5	+		
	hg 40	0.503	0.180	5	-		
	hg 42	0.003	0.934	5	+		
	hg 43	0.749	0.058	5	+	*	

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Pisgah Hurricane Gap Chestnut Oak							
	hg 02	0.593	0.128	5	+		
	hg 04	0.446	0.218	5	+		
	hg 06	0.359	0.285	5	+		
	hg 09	0.341	0.416	4	+		
	hg 10	0.735	0.063	5	+	*	
	hg 12	0.305	0.335	5	+		
	hg 13	0.732	0.065	5	+	*	
	hg 14	0.695	0.079	5	+		
	hg 17	0.663	0.093	5	+	*	
	hg 19	0.809	0.038	5	+	*	*
	hg 20	0.784	0.046	5	+	*	*
	hg 25	0.027	0.792	5	+		
	hg 28	0.918	0.010	5	+	*	*
	hg 30	0.865	0.022	5	-	*	*
	hg 31	0.541	0.157	5	+		
	hg 35	0.314	0.326	5	+		
	hg 36	0.226	0.419	5	+		
	hg 41	0.020	0.820	5	+		
Pisgah Hurricane Gap White Oak							
	hg 03	0.049	0.721	5	+		
	hg 05	0.000	1.000	5			
	hg 29	0.024	0.806	5	+		
	hg 33	0.269	0.370	5	+		
	hg 44	0.026	0.796	5	-		
Pisgah Hard Times Scarlet Oak							
	ht 13	0.005	0.899	6	-		
	ht 14	0.039	0.708	6	-		
	ht 25	0.169	0.492	5	-		
	ht 47	0.473	0.200	5	-		
	ht 49	0.020	0.820	5	+		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	p	n	*sign*	$p < 0.1$	$p < 0.05$
Pisgah Hard Times Chestnut Oak							
	ht 01	0.015	0.819	6	+		
	ht 07	0.029	0.746	6	-		
	ht 08	0.162	0.428	6	+		
	ht 15	0.041	0.702	6	+		
	ht 16	0.030	0.741	6	+		
	ht 19	0.144	0.458	6	+		
	ht 20	0.739	0.028	6	+	*	*
	ht 26	0.002	0.930	6	+		
	ht 27	0.002	0.940	6	-		
	ht 28	0.026	0.761	6	+		
	ht 30	0.015	0.817	6	+		
	ht 34	0.247	0.316	6	-		
	ht 41	0.033	0.731	6	+		
	ht 44	0.224	0.343	6	+		
	ht 45	0.022	0.022	6	+		
Pisgah Hard Times White Oak							
	ht 02	0.007	0.871	6	+		
	ht 04	0.123	0.496	6	+		
	ht 09	0.336	0.228	6	+		
	ht 11	0.058	0.645	6	+		
	ht 12	0.177	0.406	6	+		
	ht 17	0.258	0.303	6	+		
	ht 18	0.033	0.729	6	+		
	ht 21	0.020	0.788	6	-		
	ht 22	0.118	0.505	6	+		
	ht 23	0.346	0.220	6	+		
	ht 29	0.002	0.937	6	-		
	ht 32	0.243	0.320	6	+		
	ht 33	0.054	0.659	6	-		
	ht 35	0.020	0.788	6	+		
	ht 36	0.000	0.977	5	-		
	ht 37	0.007	0.877	6	-		
	ht 40	0.311	0.250	6	+		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
	ht 42	0.073	0.604	6	+		
	ht 43	0.128	0.486	6	+		
	ht 46	0.201	0.372	6	+		
	ht 48	0.158	0.507	5	+		
	ht 51	0.025	0.798	5	-		
Pisgah Mill Ridge Scarlet Oak							
	mr 03	0.218	0.428	5	-		
	mr 04	0.071	0.664	5	-		
	mr 05	0.268	0.372	5	-		
	mr 08	0.009	0.876	5	+		
	mr 13	0.083	0.638	5	-		
	mr 15	0.312	0.328	5	-		
	mr 19	0.651	0.099	5	-	*	
	mr 25	0.236	0.406	5	-		
	mr 27	0.216	0.430	5	-		
	mr 33	0.595	0.127	5	-		
	mr 34	0.794	0.043	5	-	*	*
	mr 35	0.255	0.386	5	-		
Pisgah Mill Ridge Chestnut Oak							
	mr 06	0.163	0.500	5	+		
	mr 10	0.441	0.222	5	+		
	mr 11	0.455	0.211	5	+		
	mr 12	0.267	0.484	4	-		
	mr 16	0.028	0.787	5	+		
	mr 21	0.253	0.388	5	+		
	mr 22	0.000	0.984	5			
	mr 23	0.020	0.820	5	+		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Pisgah Mill Ridge White Oak							
	mr 14	0.101	0.602	5	+		
	mr 17	0.086	0.631	5	+		
	mr 18	0.148	0.523	5	-		
	mr 20	0.001	0.962	5	-		
	mr 24	0.166	0.496	5	-		
	mr 26	0.028	0.789	5	-		
	mr 28	0.058	0.696	5	+		
	mr 29	0.229	0.415	5	+		
	mr 30	0.038	0.754	5	+		
	mr 31	0.207	0.441	5	+		
	mr 32	0.115	0.576	5	+		
Pisgah Old Gate Scarlet Oak							
	og 01	0.416	0.240	5	-		
	og 04	0.002	0.946	5	+		
	og 06	0.821	0.034	5	-	*	*
	og 12	0.462	0.207	5	-		
	og 14	0.463	0.206	5	-		
	og 16	0.008	0.885	5	-		
	og 20	0.165	0.497	5	-		
	og 21	0.035	0.762	5	-		
	og 23	0.122	0.564	5	-		
	og 24	0.361	0.284	5	-		
	og 26	0.354	0.290	5	-		
	og 31	0.016	0.837	5	-		
	og 32	0.922	0.010	5	+	*	*
Pisgah Old Gate Chestnut Oak							
	og 07	0.102	0.601	5	+		
	og 08	0.006	0.898	5	-		
	og 10	0.058	0.697	5	-		
	og 13	0.024	0.803	5	+		
	og 17	0.058	0.698	5	+		
	og 18	0.125	0.559	5	-		
	og 19	0.014	0.851	5	-		
	og 22	0.002	0.949	5	+		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Pisgah Rice Pinnacle Scarlet Oak							
	rp 03	0.659	0.095	5	-	*	
	rp 16	0.020	0.820	5	+		
	rp 17	0.229	0.414	5	+		
	rp 18	0.221	0.425	5	-		
	rp 22	0.326	0.315	5	+		
	rp 26	0.044	0.736	5	-		
	rp 27	0.455	0.211	5	+		
	rp 28	0.181	0.475	5	-		
	rp 29	0.178	0.479	5	-		
	rp 30	0.089	0.626	5	+		
	rp 31	0.403	0.250	5	+		
	rp 33	0.158	0.508	5	-		
	rp 34	0.080	0.645	5	-		
	rp 35	0.299	0.340	5	+		
	rp 36	0.003	0.932	5	-		
	rp 39	0.043	0.739	5	-		
	rp 40	0.175	0.483	5	+		
Pisgah Rice Pinnacle White Oak							
	rp 01	0.032	0.773	5	+		
	rp 02	0.051	0.715	5	+		
	rp 04	0.646	0.101	5	+		
	rp 05	0.001	0.958	5	-		
	rp 06	0.043	0.739	5	+		
	rp 07	0.001	0.967	5	+		
	rp 08	0.000	0.975	5	-		
	rp 09	0.176	0.481	5	+		
	rp 10	0.116	0.575	5	+		
	rp 13	0.355	0.289	5	+		
	rp 14	0.042	0.742	5	-		
	rp 15	0.070	0.668	5	+		
	rp 19	0.059	0.693	5	+		
	rp 20	0.081	0.642	5	-		
	rp 21	0.156	0.510	5	+		
	rp 23	0.158	0.508	5	-		
	rp 25	0.093	0.617	5	+		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Pisgah South Ridge Northern Red Oak							
	sr 01	0.002	0.949	5	+		
	sr 02	0.266	0.374	5	+		
	sr 03	0.012	0.859	5	+		
	sr 04	0.056	0.702	5	-		
	sr 05	0.020	0.820	5	+		
	sr 06	0.107	0.590	5	+		
	sr 10	0.065	0.678	5	-		
	sr 11	0.802	0.040	5	-	*	*
	sr 14	0.045	0.732	5	-		
	sr 16	0.379	0.269	5	+		
	sr 26	0.315	0.325	5	-		
	sr 46	0.277	0.362	5	-		
Pisgah South Ridge Scarlet Oak							
	sr 20	0.009	0.879	5	+		
	sr 21	0.044	0.734	5	-		
	sr 28	0.313	0.327	5	-		
	sr 30	0.410	0.245	5	-		
	sr 32	0.189	0.464	5	-		
	sr 33	0.295	0.344	5	-		
	sr 40	0.133	0.546	5	-		
	sr 42	0.051	0.855	3	-		

Table B-1 (continued). Summary correlation statistics for the tree level analysis with USFS mast data.

Forest, Site, Species	*Sample ID*	r^2	*p*	*n*	*sign*	$p < 0.1$	$p < 0.05$
Pisgah South Ridge Chestnut Oak							
	sr 07	0.122	0.564	5	+		
	sr 08	0.820	0.034	5	+	*	*
	sr 13	0.494	0.186	5	+		
	sr 17	0.516	0.171	5	-		
	sr 19	0.480	0.195	5	+		
	sr 23	0.047	0.727	5	-		
	sr 34	0.333	0.308	5	+		
	sr 36	0.088	0.628	5	+		
	sr 38	0.000	0.977	5			
	sr 43	0.360	0.285	5	+		
	sr 44	0.045	0.731	5	-		
	sr 45	0.036	0.761	5	-		
	sr 49	0.056	0.703	5	+		
	sr 53	0.020	0.820	5	-		
	sr 54	0.283	0.356	5	+		
Pisgah South Ridge White Oak							
	sr 12	0.090	0.624	5	-		
	sr 22	0.260	0.380	5	-		
	sr 24	0.131	0.550	5	-		
	sr 25	0.013	0.855	5	-		
	sr 29	0.066	0.678	5	+		
	sr 31	0.010	0.874	5	-		
	sr 39	0.517	0.171	5	-		

Appendix C: The regression results from the stand-level mast analysis with the USFS data

This appendix contains the regression results at the stand level between the tree-ring index chronologies and that stand's USFS mast data. The r^2 shows the amount of variance in the tree-level index chronologies explained by the tree-level mast data. N is the number of years of mast data for each tree in the stand. Most trees have six years of data for 1993 through 1998 and there is a minimum of 5 trees in the chronology at each stand. Because I censored the data by removing zero values for the amount of mast collected, the number of observations per test varies greatly. The site-species chronologies with significant correlations are designated by an asterisk in the last column.

Table C-1. Summary of the correlation statistics for the stand-level analysis with the USFS mast data.

Site-Species Chronology	*r*	*r^2*	*p*	*n*	*$p < 0.1$*
Buell Plot Chestnut Oak	0.004	0.000	0.987	23	
Buell Plot Northern Red Oak	0.006	0.000	0.978	22	
Buell Plot Scarlet Oak	-0.130	0.017	0.450	36	
Buell Plot White Oak	0.485	0.235	0.041	18	*
Bike Trail Black Oak	-0.141	0.020	0.474	28	
Bike Trail Northern Red Oak	0.001	0.000	0.997	28	
Bike Trail Scarlet Oak	0.066	0.004	0.761	24	
Bike Trail White Oak	0.254	0.065	0.241	23	
Burnett Gap Black Oak	0.066	0.004	0.715	33	
Burnett Gap Chestnut Oak	0.512	0.262	0.043	16	*
Burnett Gap Northern Red Oak	0.061	0.004	0.809	18	
Burnett Gap Scarlet Oak	-0.286	0.082	0.066	42	*
Burnett Gap White Oak	0.007	0.000	0.971	26	
Cohutta Chestnut Oak	-0.043	0.002	0.834	26	
Cohutta Scarlet Oak	0.019	0.000	0.934	22	
Cohutta White Oak	-0.150	0.022	0.594	15	
Green's Lick Black Oak	-0.117	0.014	0.634	19	
Green's Lick Chestnut Oak	0.029	0.001	0.868	35	
Green's Lick Northern Red Oak	-0.076	0.006	0.507	78	
Green's Lick White Oak	-0.129	0.017	0.400	45	

Table C-1 (continued). Summary of the correlation statistics for the stand-level analysis with the USFS mast data.

Site-Species Chronology	*r*	r^2	*p*	*n*	$p < 0.1$
Hurricane Gap Chestnut Oak	-0.288	0.083	0.098	34	*
Hurricane Gap Northern Red Oak	0.454	0.206	0.020	26	*
Hurricane Gap White Oak	-0.312	0.097	0.414	9	
Hiawassee B White Oak	0.558	0.311	0.025	16	*
Hiawassee C Black Oak	0.071	0.005	0.669	39	
Hiawassee C Chestnut Oak	0.235	0.055	0.181	34	
Hiawassee C Scarlet Oak	-0.192	0.037	0.347	26	
Hard Times Chestnut Oak	0.082	0.007	0.654	32	
Hard Times Scarlet Oak	-0.113	0.013	0.646	19	
Hard Times White Oak	0.080	0.006	0.557	56	
Jackson Farm Black Oak	0.164	0.027	0.363	33	
Jackson Farm Chestnut Oak	-0.425	0.181	0.009	37	*
Jackson Farm Northern Red Oak	-0.485	0.235	0.030	20	*
Jackson Farm Scarlet Oak	-0.243	0.059	0.222	27	
Jackson Farm White Oak	-0.372	0.139	0.025	36	*
Mill Ridge Chestnut Oak	-0.139	0.019	0.666	12	
Mill Ridge Scarlet Oak	-0.205	0.042	0.251	33	
Mill Ridge White Oak	0.169	0.029	0.429	24	
Old Gate Chestnut Oak	0.089	0.008	0.743	16	
Old Gate Scarlet Oak	-0.330	0.109	0.022	48	*
Rice Pinnacle Scarlet Oak	0.047	0.002	0.780	38	
Rice Pinnacle White Oak	0.068	0.005	0.677	40	
South Ridge Chestnut Oak	0.011	0.000	0.954	28	
South Ridge Northern Red Oak	-0.023	0.001	0.879	45	
South Ridge Scarlet Oak	-0.286	0.082	0.235	19	
South Ridge White Oak	-0.333	0.111	0.192	17	
Tallulah Chestnut Oak	0.194	0.038	0.755	5	
Tallulah Northern Red Oak	-0.111	0.012	0.605	24	
Tallulah White Oak	-0.182	0.033	0.696	7	
Tellico Black Oak	-0.453	0.205	0.00002	82	*
Tellico Chestnut Oak	-0.261	0.068	0.044	60	*
Tellico Northern Red Oak	0.319	0.102	0.042	41	*
Tellico Scarlet Oak	-0.106	0.011	0.412	62	
Tellico White Oak	-0.378	0.143	0.007	50	*
Work Center White Oak	0.166	0.027	0.486	20	

Appendix D: The significant regression plots from the stand level mast analysis with the USFS data

Out of 55 site-species chronologies, 14 (25%) correlated significantly with USFS tree level mast data. The regression plots, regression equation, variance explained, significance, and sample size are presented in the following graphics.

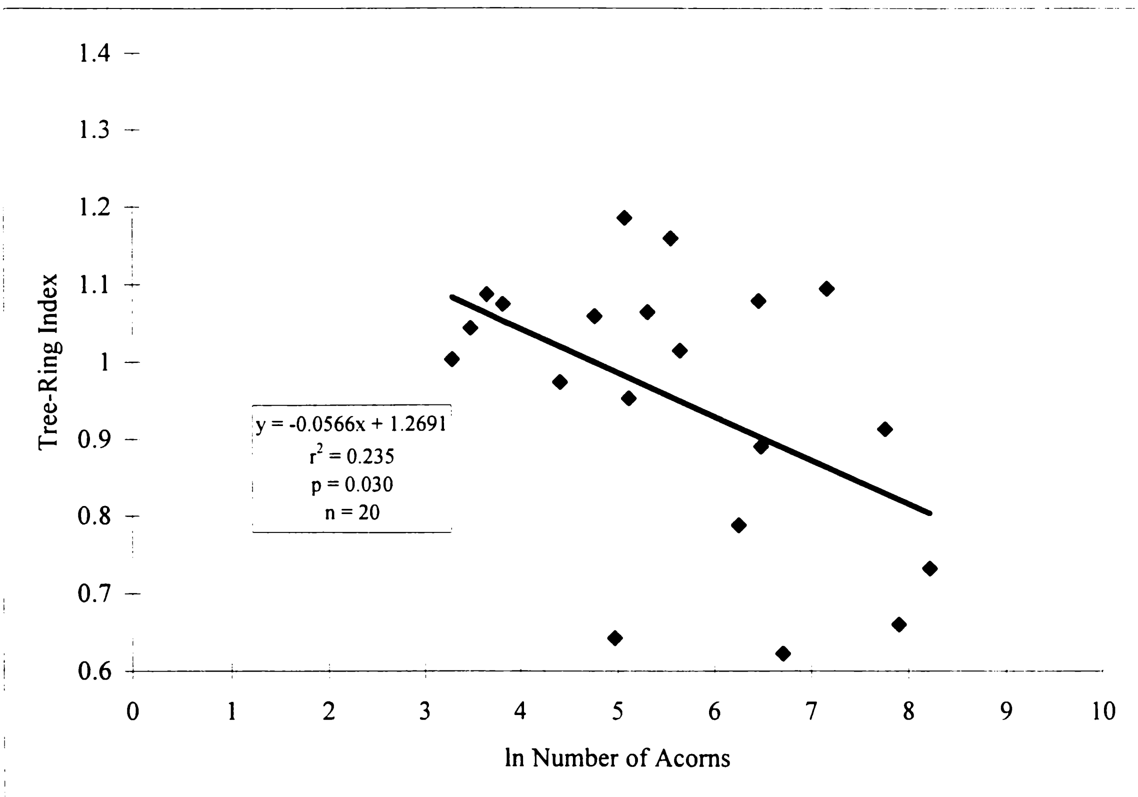

Figure D-1. Correlation of the Jackson Farm northern red oak index chronology to USFS mast data at the tree level.

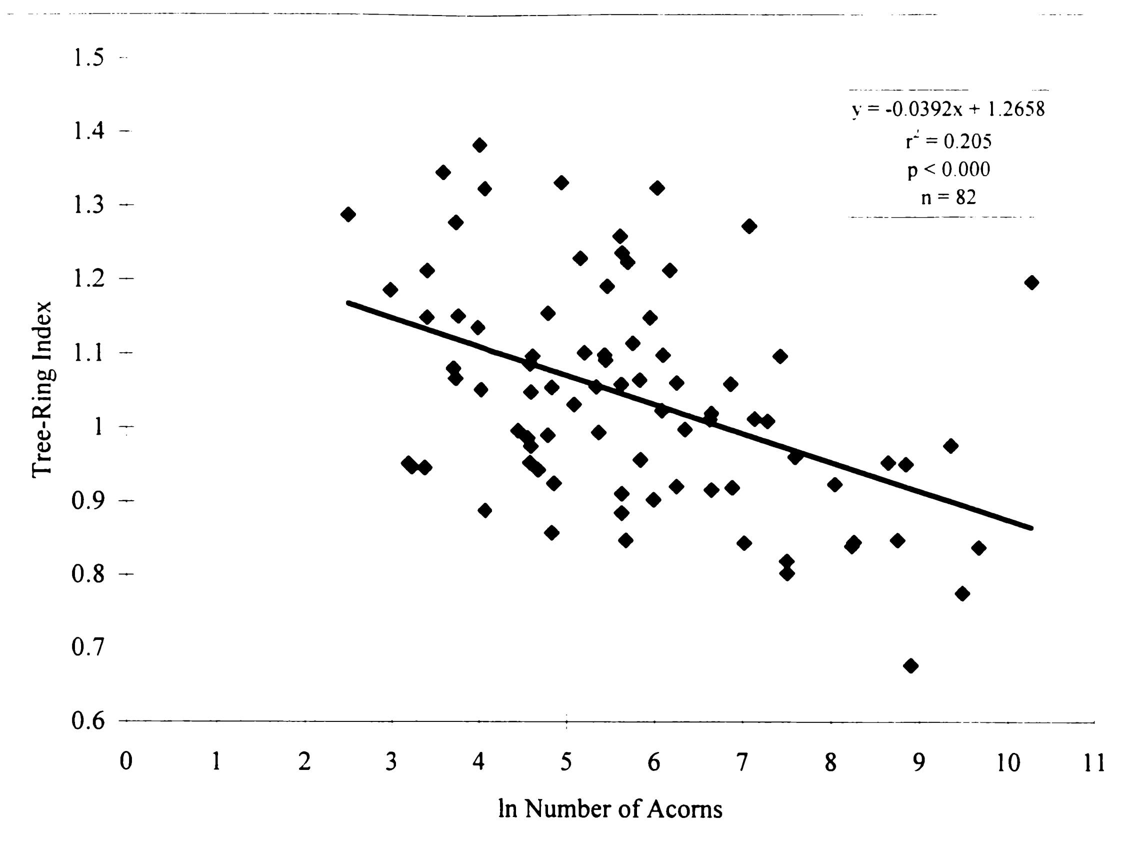

Figure D-2. Correlation of the Tellico black oak index chronology to USFS mast data at the tree level.

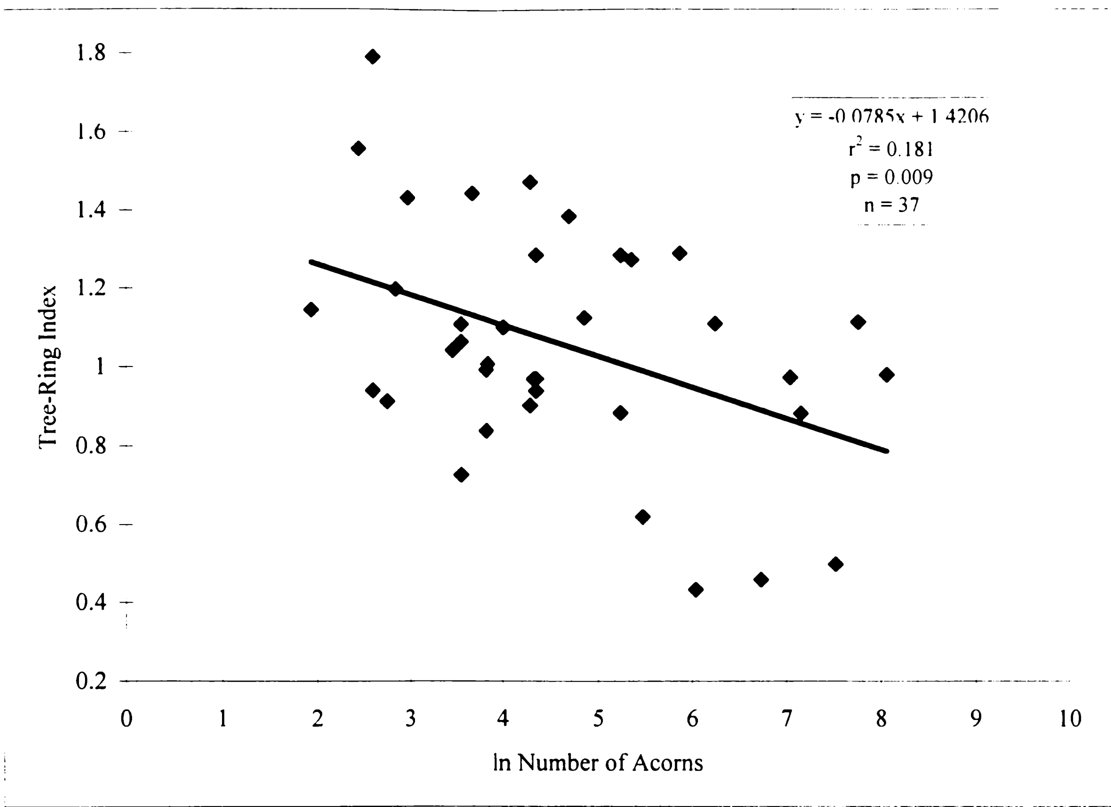

Figure D-3. Correlation of the Jackson Farm chestnut oak index chronology to USFS mast data at the tree level.

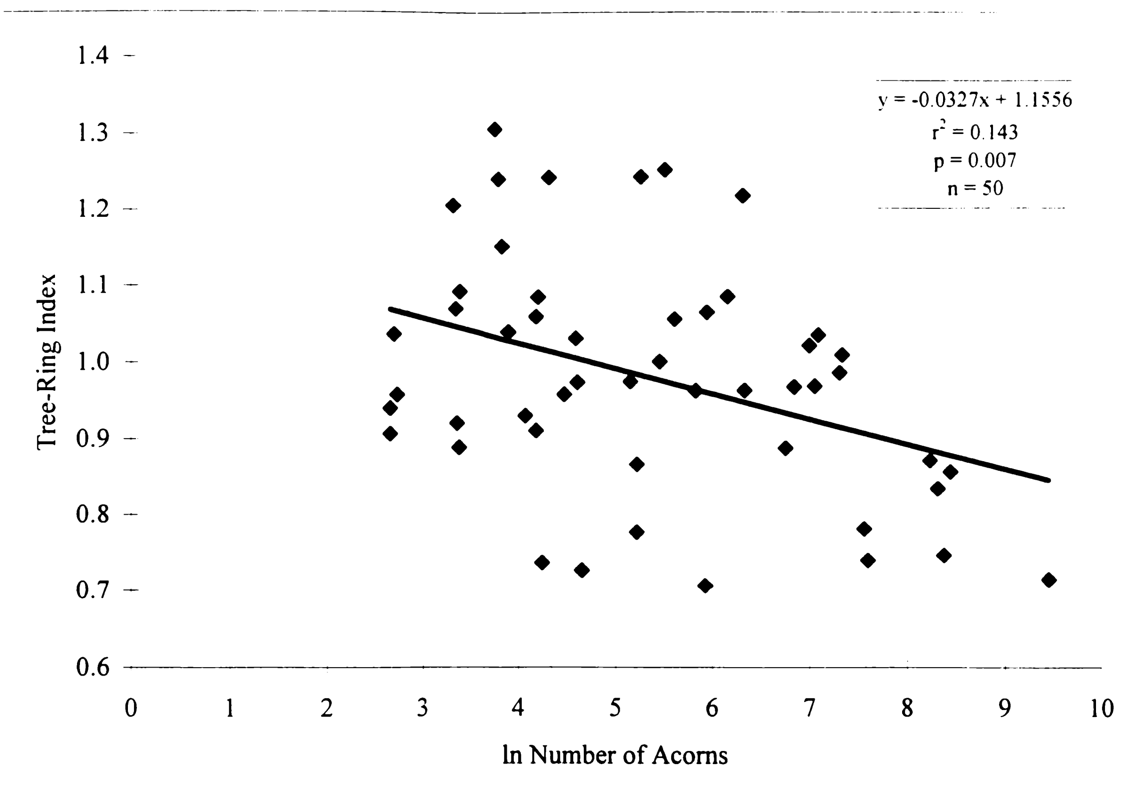

Figure D-4. Correlation of the Tellico scarlet oak index chronology to USFS mast data at the tree level.

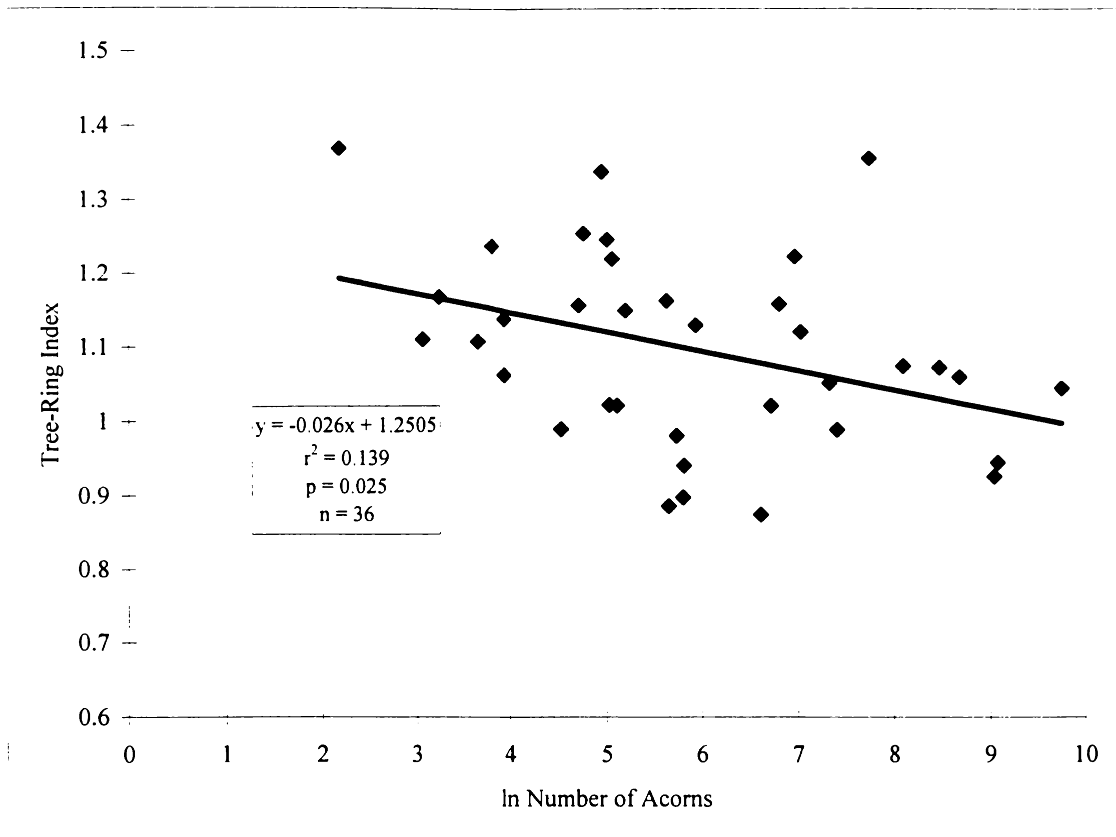

Figure D-5. Correlation of the Jackson Farm white oak index chronology to USFS mast data at the tree level.

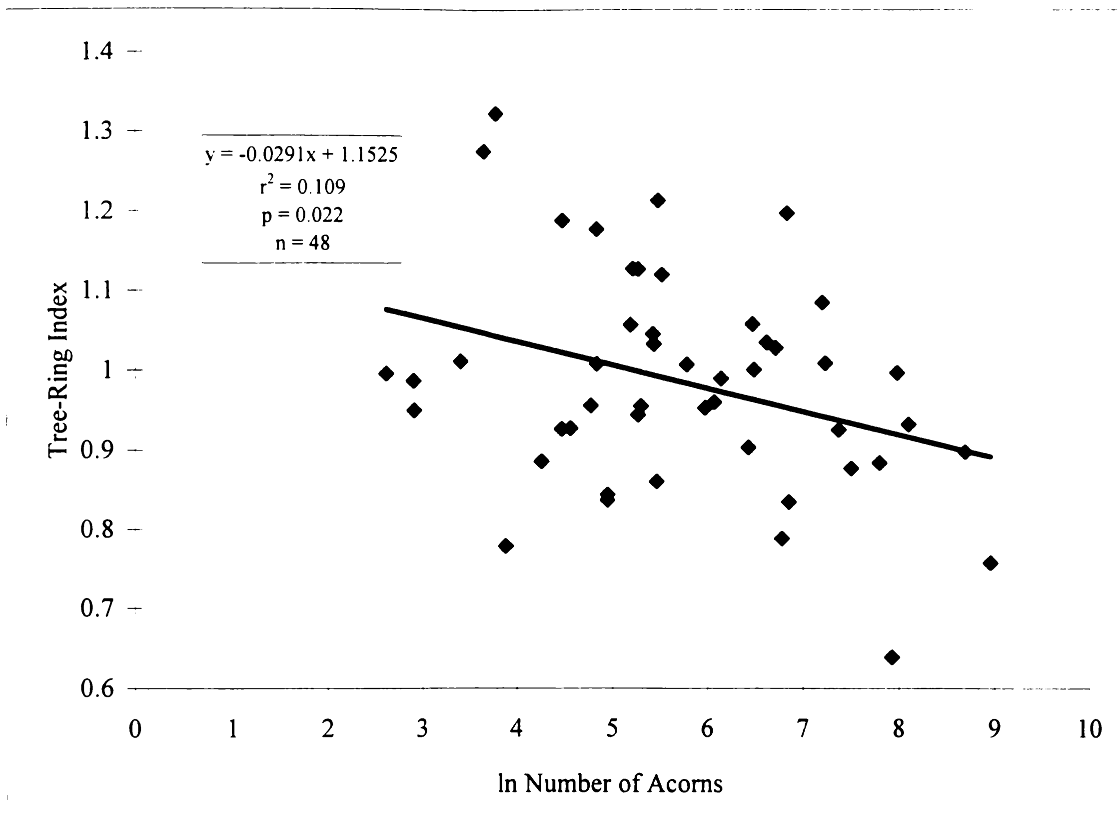

Figure D-6. Correlation of the Old Gate scarlet oak index chronology to USFS mast data at the tree level.

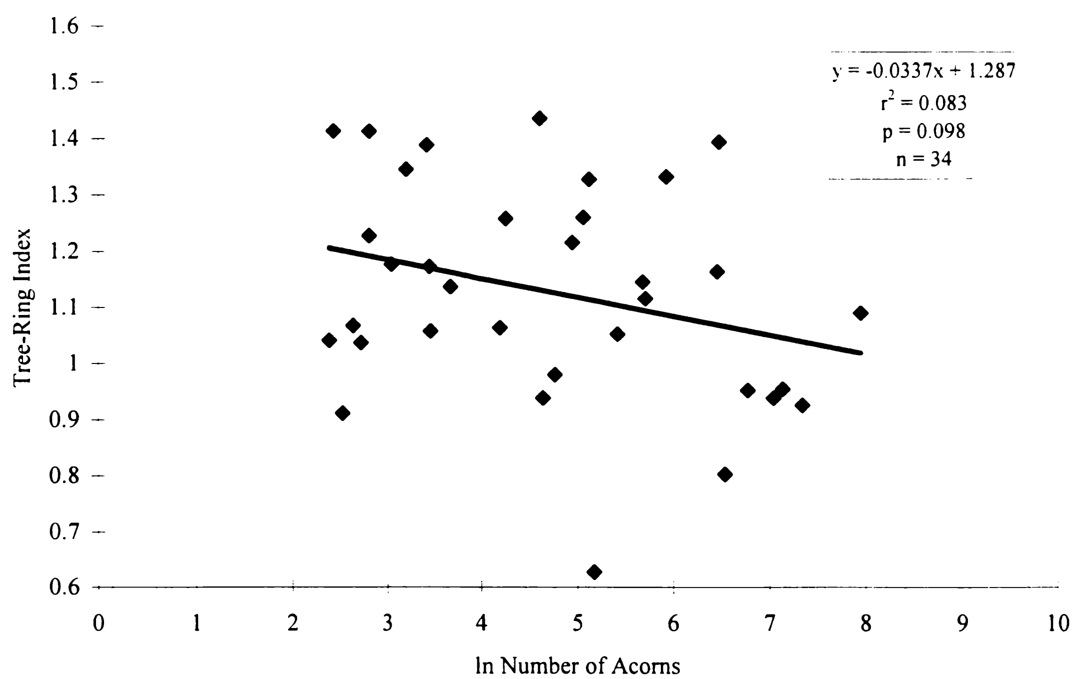

Figure D-7. Correlation of the Hurricane Gap chestnut oak index chronology to USFS mast data at the tree level.

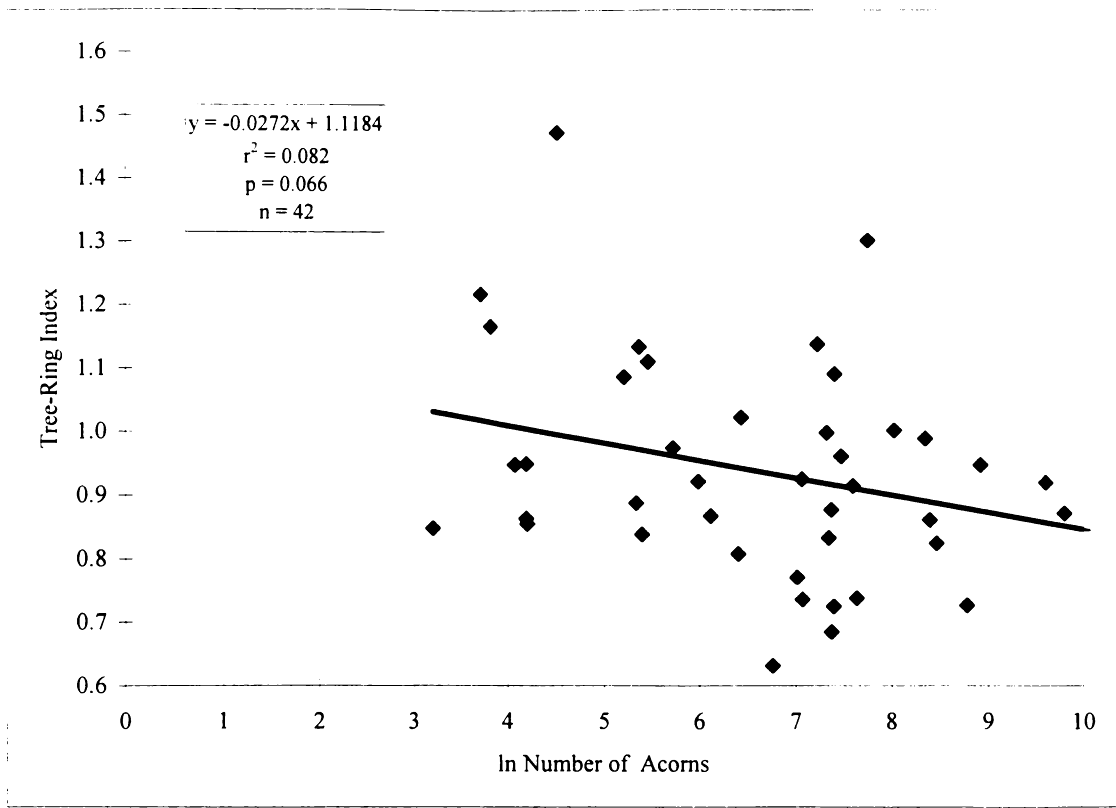

Figure D-8. Correlation of the Burnett Gap scarlet oak index chronology to USFS mast data at the tree level.

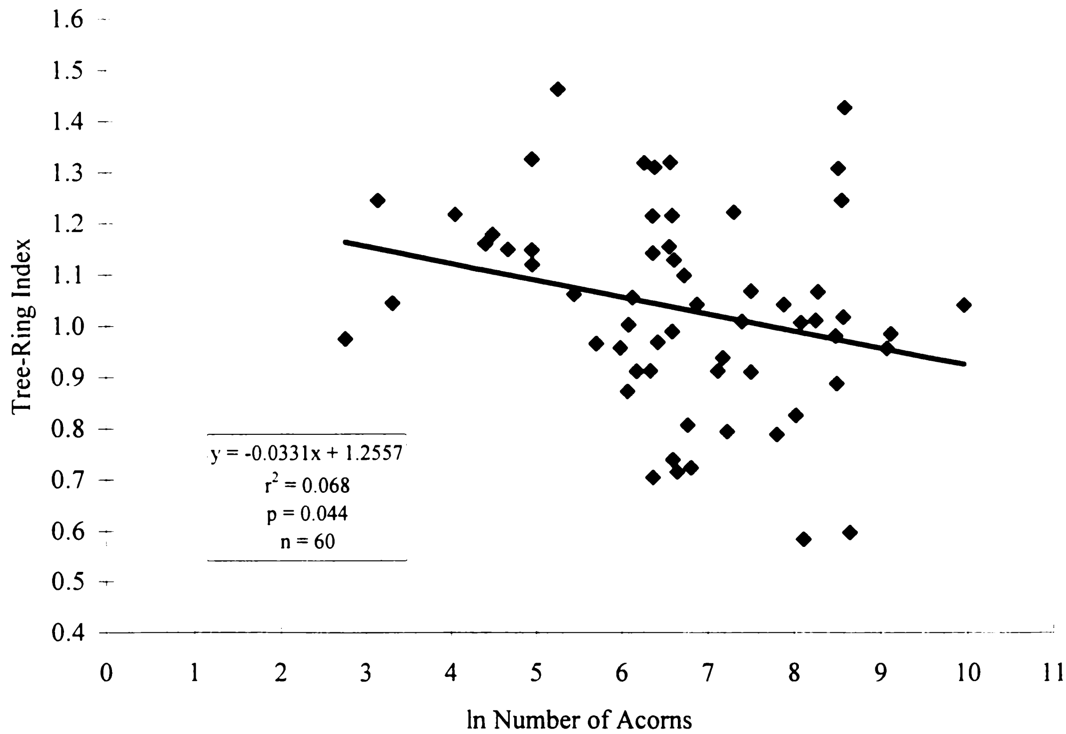

Figure D-9. Correlation of the Tellico chestnut oak index chronology to USFS mast data at the tree level.

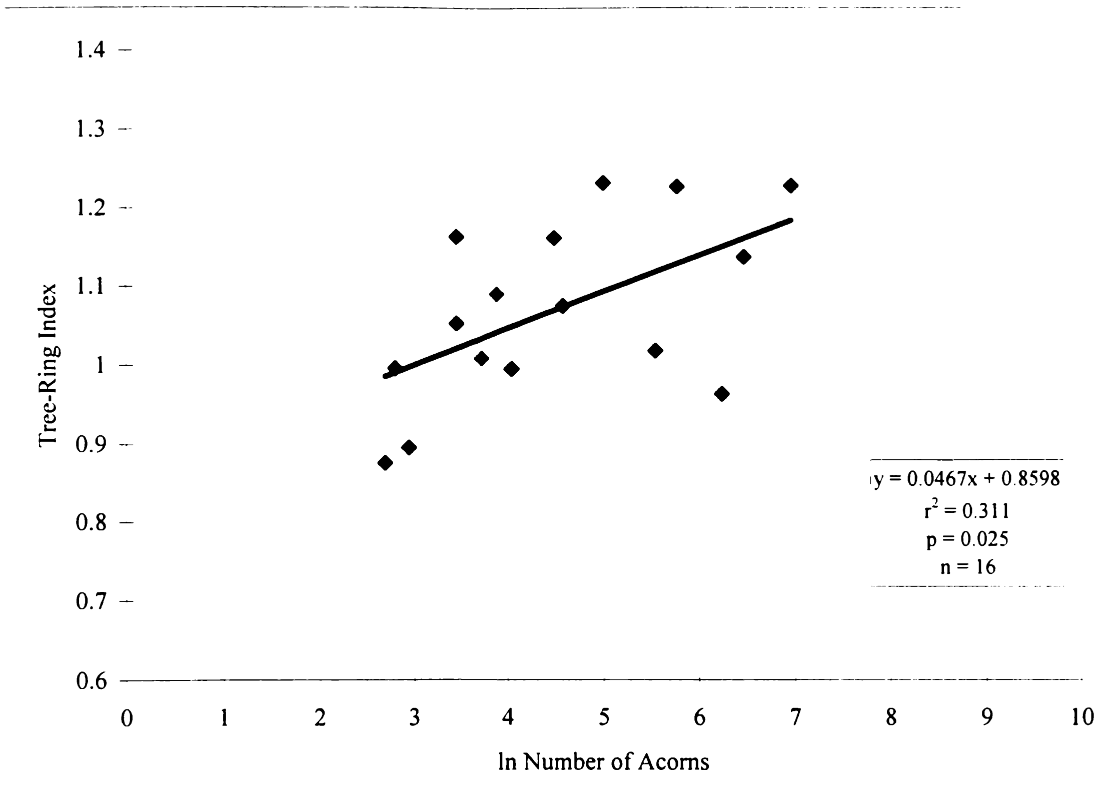

Figure D-10. Correlation of the Hiawasee B white oak index chronology to USFS mast data at the tree level.

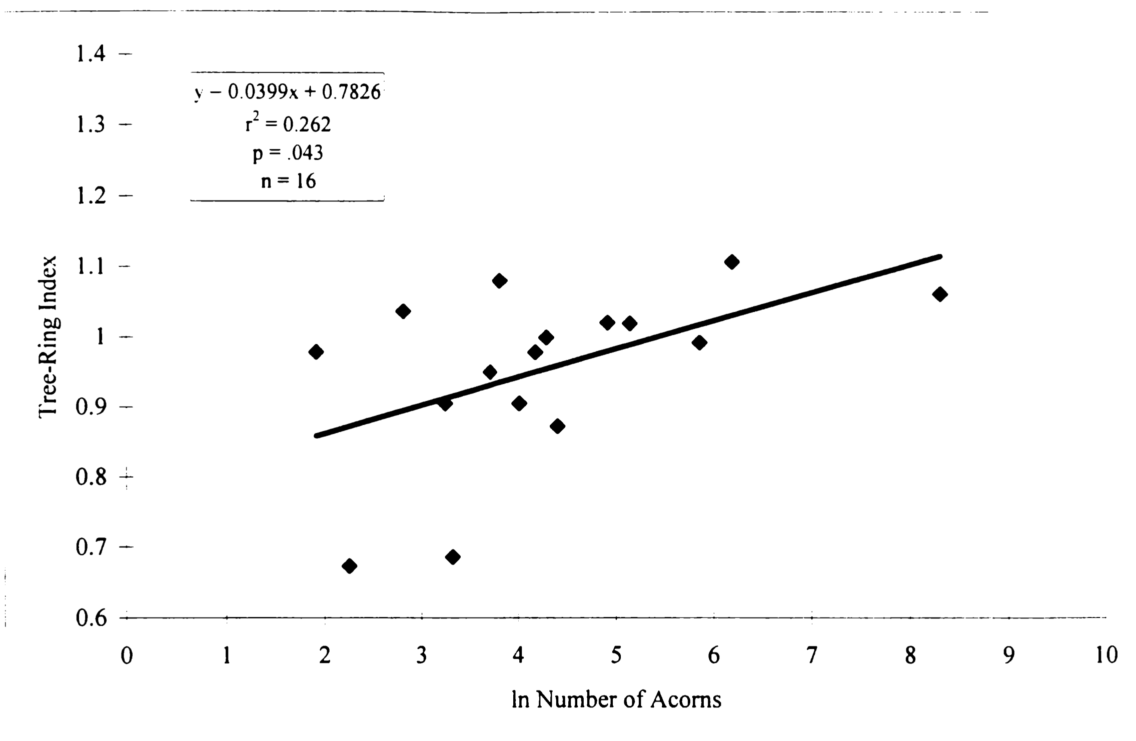

Figure D-11. Correlation of the Burnett Gap chestnut oak index chronology to USFS mast data at the tree level.

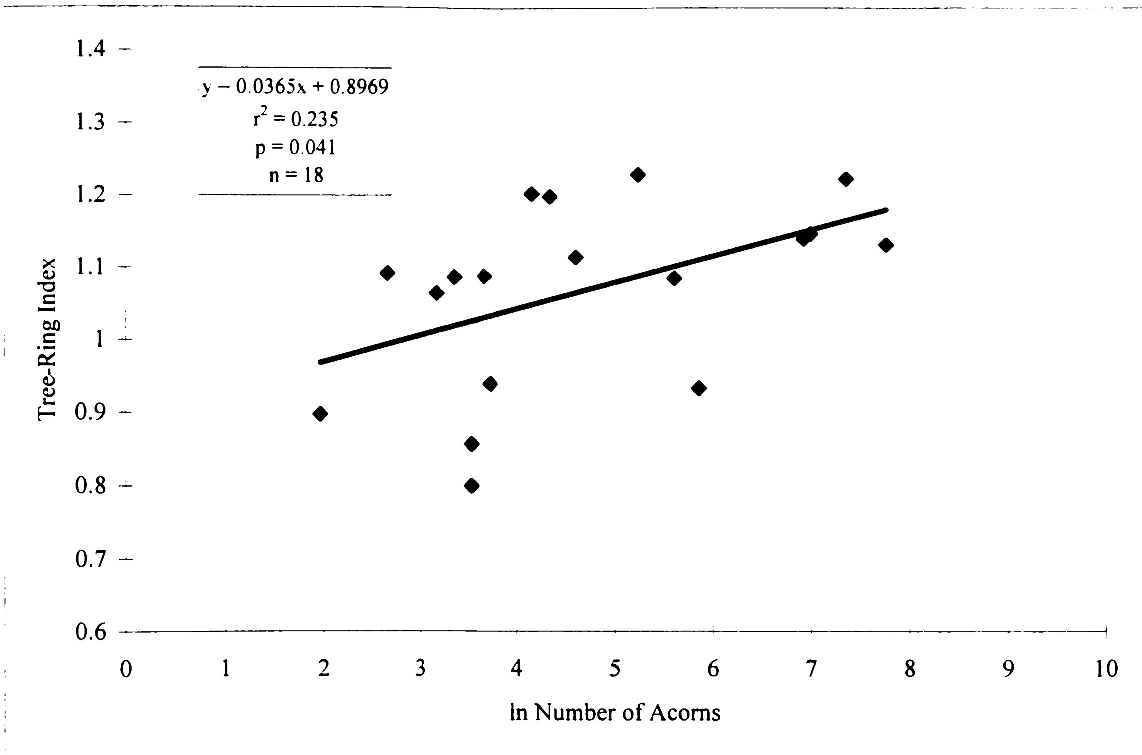

Figure D-12. Correlation of the Buell Plot white oak index chronology to USFS mast data at the tree level.

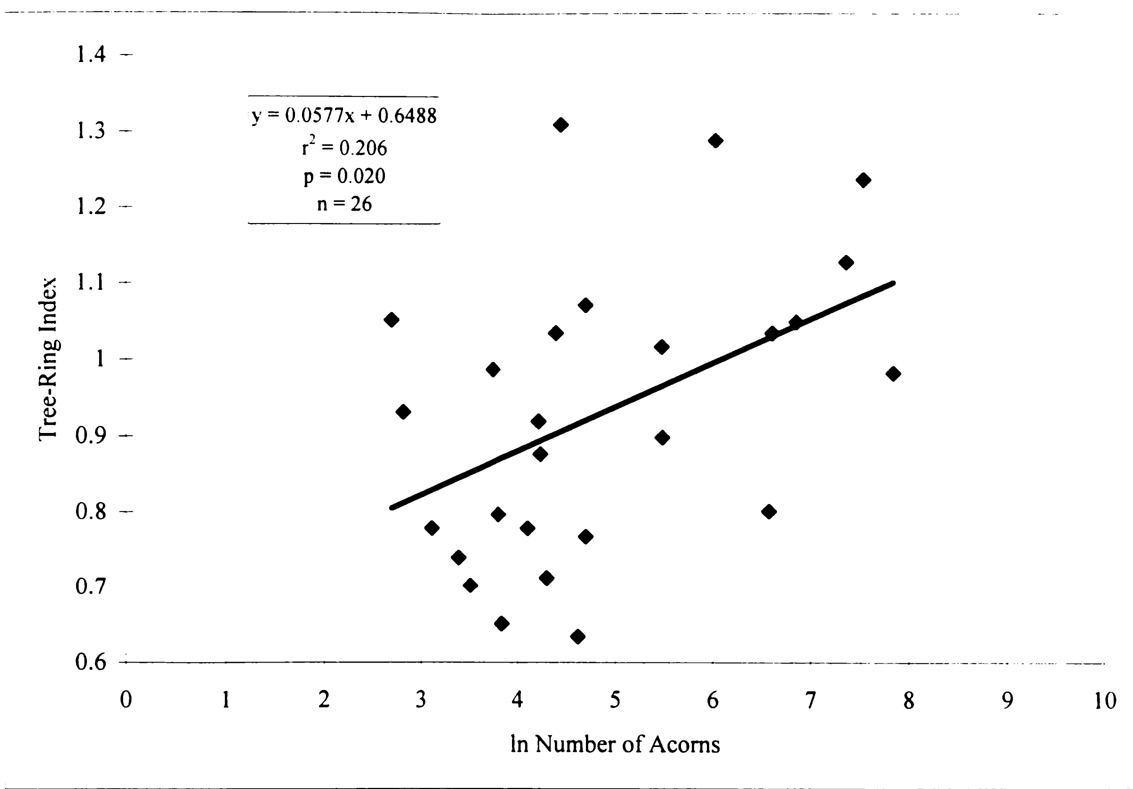

Figure D-13. Correlation of the Hurricane Gap northern red oak index chronology to USFS mast data at the tree level.

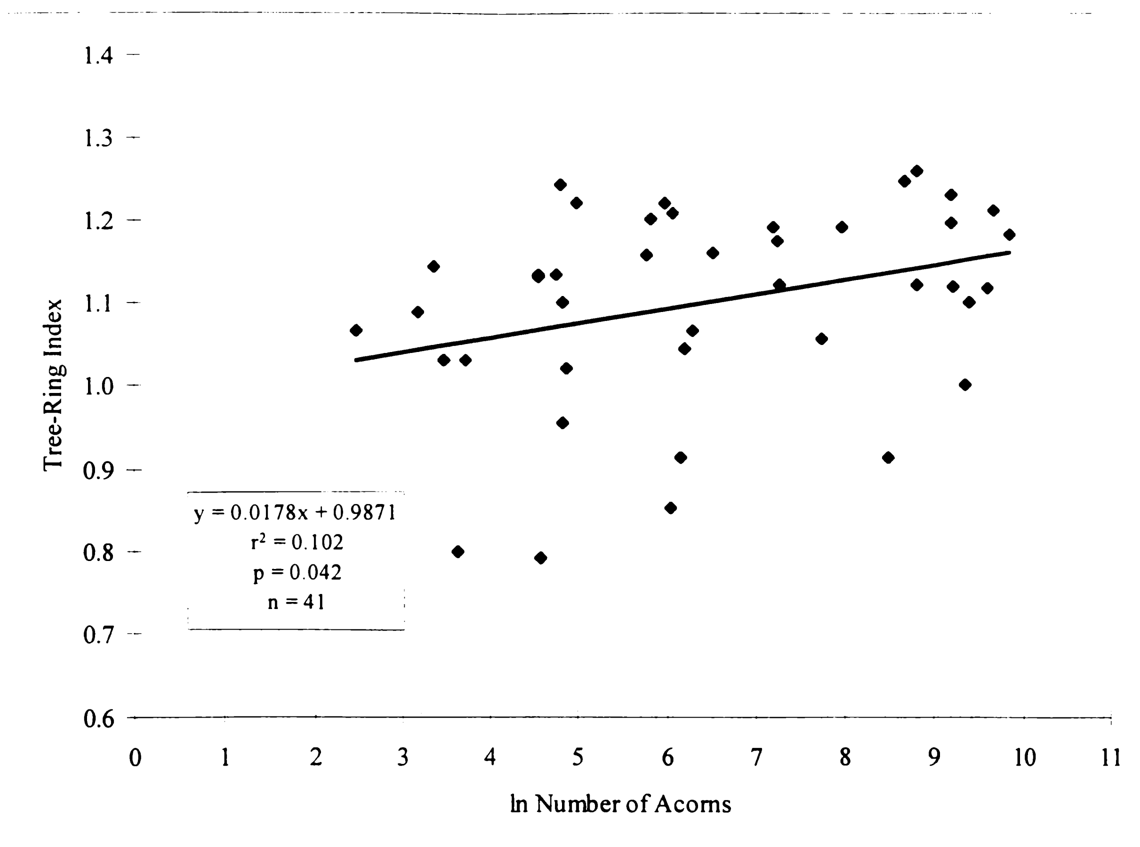

Figure D-14. Correlation of the Tellico white oak index chronology to USFS mast data at the tree level.

Appendix E: Lagged years analysis of tree-ring residuals versus stand level SWRA mast data.

We analyzed the six site-species chronologies and the one regional species chronology that correlated significantly with SWRA mast, to determine if the trees were storing reserves at the expense of radial growth for years preceding the production of heavy mast crops. We compared lagged years (from –10 to +5) of tree-ring residuals to the SWRA mast data for the current year.

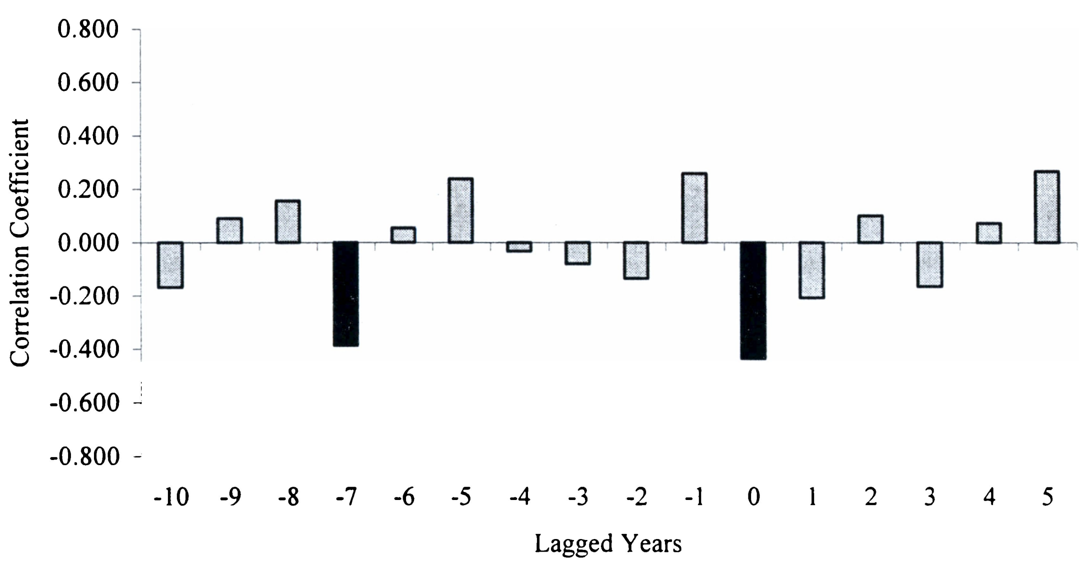

Figure E-1. Lagged years of tree-ring residuals versus the southeastern regional-level mast for the regional white oak chronology. The significant years are shaded in black (p < 0.1).

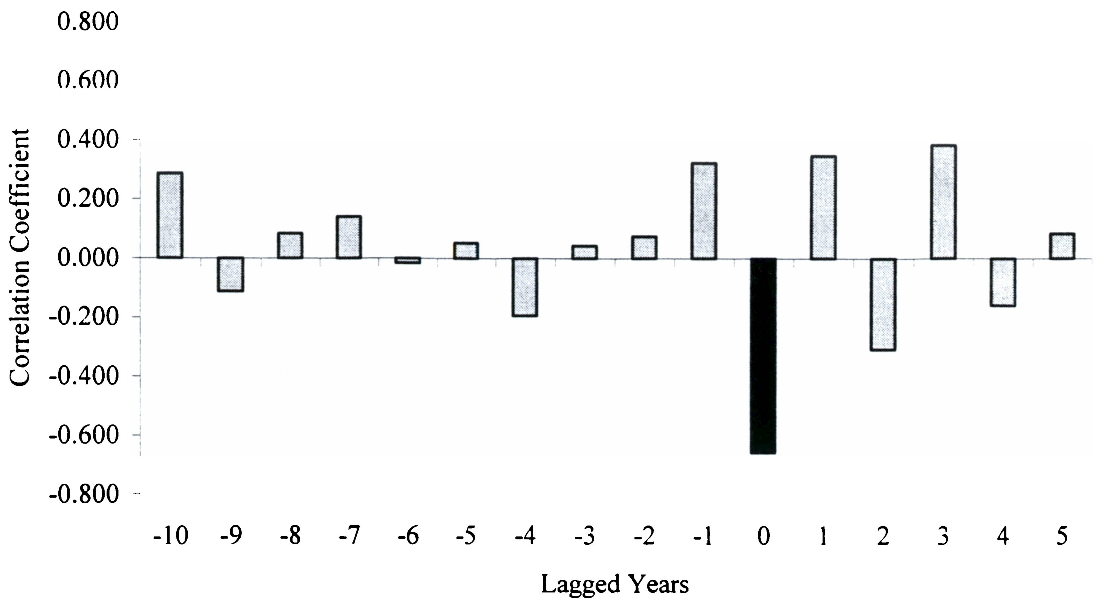

Figure E-2. Lagged years of tree-ring residuals versus stand-level mast for the Tellico white oak chronology. The significant years are shaded in black ($p < 0.1$).

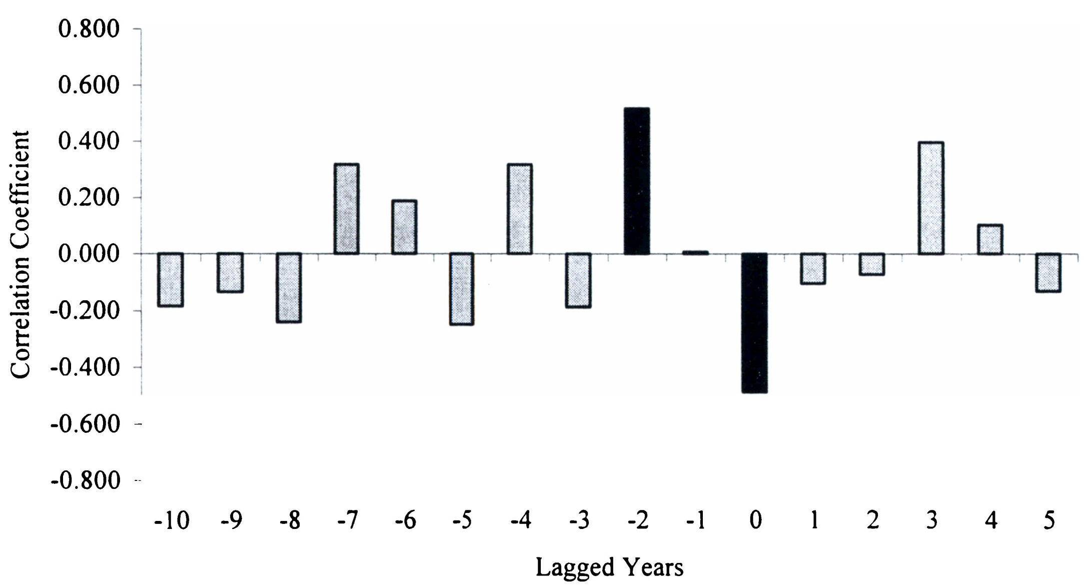

Figure E-3. Lagged years of tree-ring residuals versus stand-level mast for the Jackson Farm white oak chronology. The significant years are shaded in black ($p < 0.1$).

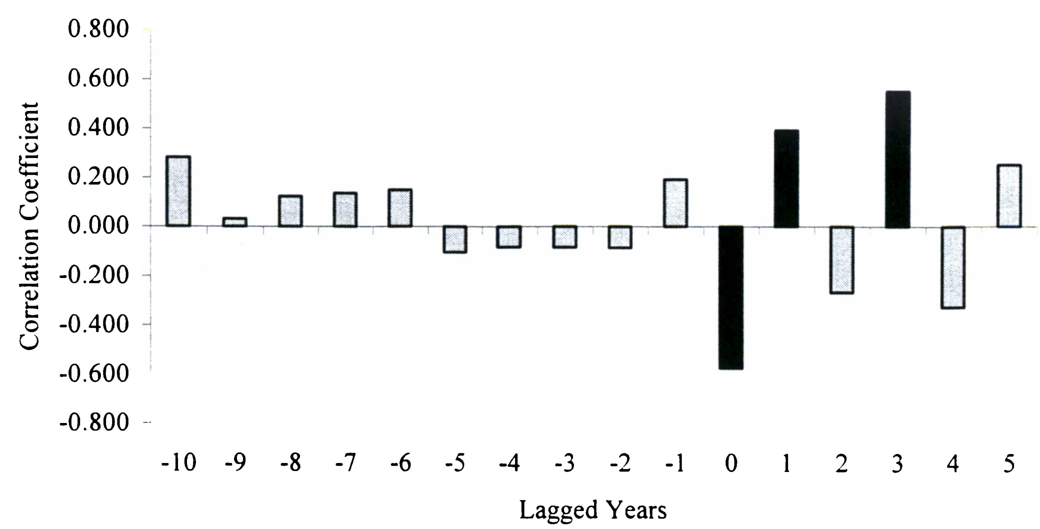

Figure E-4. Lagged years of tree-ring residuals versus stand-level mast for the Tellico chestnut oak chronology. The significant years are shaded in black ($p < 0.1$).

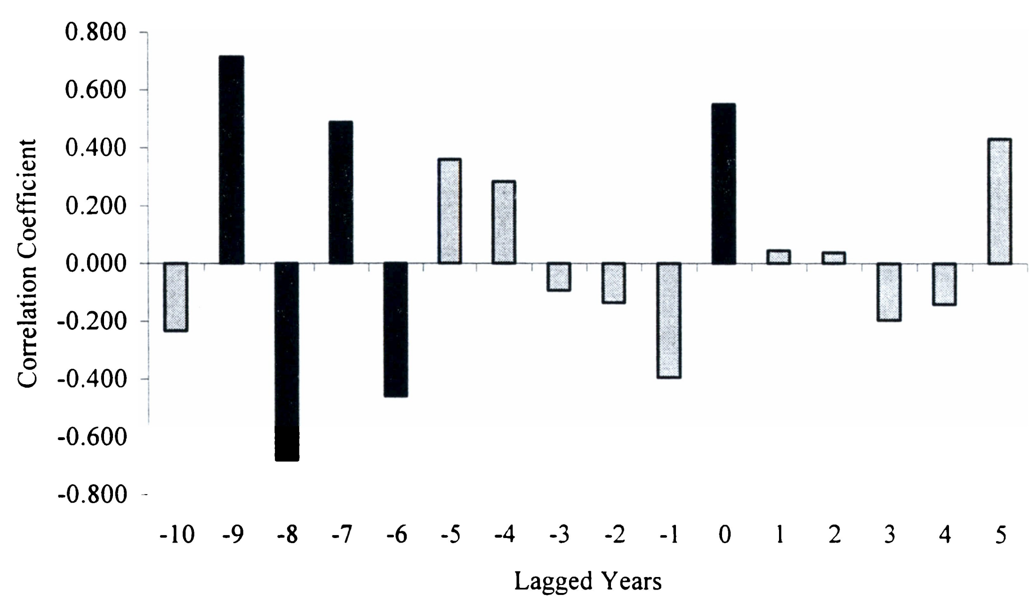

Figure E-5. Lagged years of tree-ring residuals versus stand-level mast for the Cohutta chestnut oak chronology. The significant years are shaded in black ($p < 0.1$).

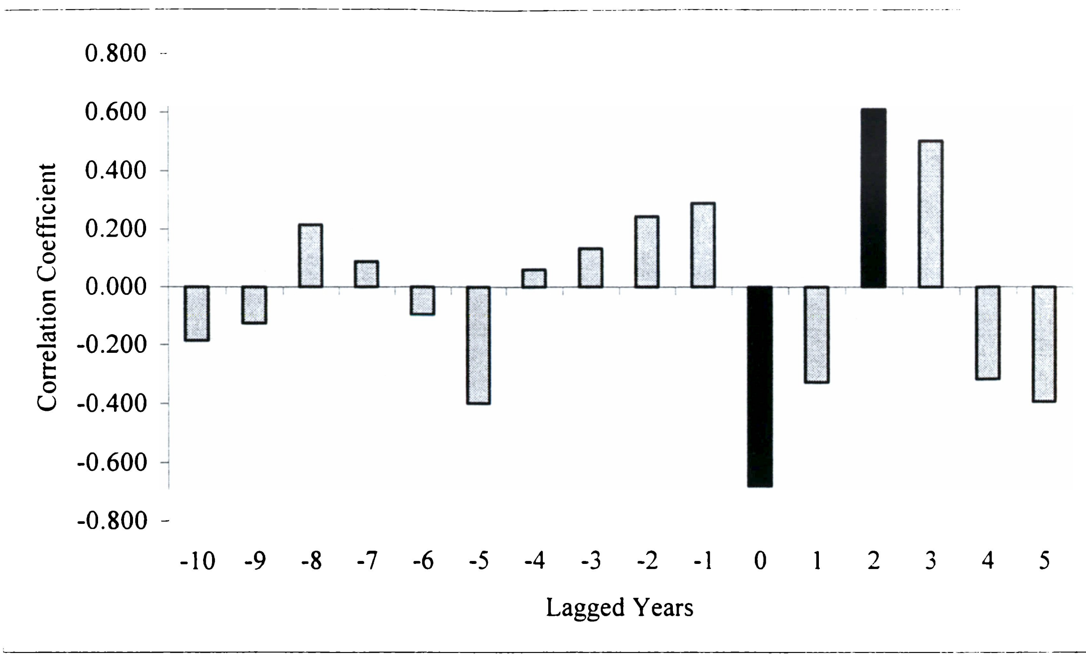

Figure E-6. Lagged years of tree-ring residuals versus stand-level mast for the Rice Pinnacle scarlet oak chronology. The significant years are shaded in black ($p < 0.1$).

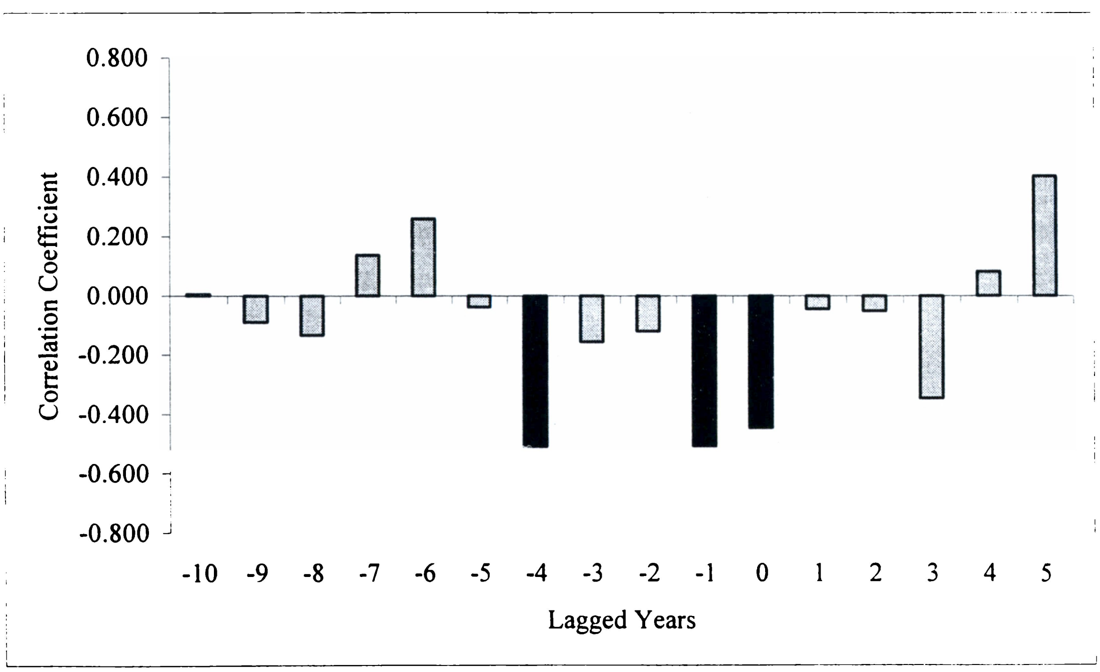

Figure E-7. Lagged years of tree-ring residuals versus stand-level mast for the Burnett Gap scarlet oak chronology. The significant years are shaded in black ($p < 0.1$).

Vita

James H. Speer was born in Boston, Massachusetts on October 13, 1971. He was raised in Phoenix, Arizona and graduated from Moon Valley high school in 1989. He started college at the University of Arizona, studying Astronomy and Physics for three years before changing his major to Geology. He graduated with a Bachelor of Science in Geosciences in August 1994. Jim entered the Master of Science program in Geosciences and dendrochronology through the Laboratory of Tree-Ring Research at the University of Arizona. During his master's work he was fortunate to participate in field work in Jordan, Canada, California, New Mexico, Alaska, and Arizona. He completed his master's on "A dendrochronological record of pandora moth (*Coloradia pandora*, Blake) outbreaks in central Oregon" under the advisement of Dr. Thomas W. Swetnam in August 1997. Jim was accepted into the Ph.D. program of the Geography Department at the University of Tennessee to work under Dr. Kenneth H. Orvis. During his Ph.D. work he had the opportunity to spend extensive field time in the highlands of the Dominican Republic assisting in research into the possible glacial history of the area and exploring the potential of *Pinus occidentalis* for dendrochronological research. Jim participated in many teaching experiences organized by the Tennessee Geographic Alliance, instructing K-12th grade teachers in Physical Geography. Jim was married to Karla Hansen in January 2000 and moved to St. Louis, Missouri to write his dissertation and to be with Karla while she conducted her Ph.D. work in Archaeology at Washington University. While in St. Louis, Jim taught Meteorology at Southern Illinois University at Edwardsville. In the Fall of 2001, Jim began an assistant professorship at Indiana State University in Terra Haute.